Potential for Natural Flavour Additives to Improve the Sensory Properties and Consumer Acceptance of Wine

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August 2016

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Abstract

Flavour additives are routinely used in food and beverage industries to enhance aroma and flavour intensity, mitigate undesirable attributes and/or better meet consumer expectations. In Australia, the legislation governing wine production prohibits the use of flavour additives. However, the potential for flavourings to be used to overcome sensory deficiencies, is an attractive option for both the wine industry and consumers.

This thesis explores the sensory properties, composition and consumer acceptance of flavoured wines and the impact of bottle ageing.

Three key studies were undertaken:

1. An online survey to determine consumer acceptance of and attitudes toward the use of additives in wine and food;

2. An investigation into the impact of flavourings on the sensory profiles and consumers acceptability of flavoured wines; and

3. A maturation trial to explore the effect of bottle ageing on the composition and sensory properties of flavoured wines.

An online survey was administered nationally to determine Australian wine consumers' acceptance of the use of additives in food and wine production. Based on self-reported wine knowledge scores, consumers (n=1031) were segmented into low (n=271), medium (n=528) and high (n=232) knowledge segments. Surprisingly, irrespective of wine knowledge, consumers were significantly more accepting of natural flavourings, natural colour, and additives associated with health benefits (e.g. vitamins and minerals) than legally permitted winemaking additives (e.g. oak chips and tannins). Consumers were also asked to identify desirable flavours in wines and their responses indicated preferences for fruity characters; i.e. lemon and apple in white wines and blackcurrant and raspberry in red wines.

The influence of flavourings on wine sensory properties and consumer acceptability of flavoured wines was subsequently investigated. Based on consumer reported flavour preferences identified in the online survey, natural flavourings were added to four inexpensive commercial wines (two Chardonnay and two

Shiraz wines) to intensify selected aroma and flavour attributes. Descriptive analysis (DA) compared the sensory profiles of control and flavoured wines, and established an overall increase in the intensity of pleasurable attributes (e.g. citrus aroma or oak flavour) and/or a decrease in undesirable characters (e.g. green and earthy notes) in flavoured wines. Acceptance tests (n=218) were then held to assess consumer liking of flavoured wines. Segmentation based on individual liking scores enabled identification of three distinct clusters for each of the white and red wine tastings. For Chardonnay: Cluster (C) 1 liking was driven by passion fruit aroma; C2 by stone fruit aroma and oak flavour; and C3 by butter aroma and honey flavour. Drivers for Shiraz liking included: red fruit and confectionery aromas for C1; green aromas and oak flavour for C2; and confectionery and oak aroma for C3.

The final experiment investigated the impact of 12 months bottle ageing on the composition and sensory properties of flavoured wines. Flavour additives and control and flavoured wines were analysed by gas chromatography-mass spectrometry to identify the volatile constituents responsible for the modification of sensory profiles of flavoured wines. However, the volatile compounds identified as constituents of flavour additives were either not detected in flavoured wines or were present at similar concentrations to those of corresponding control wines. DA of control and flavoured wines was performed after bottling (t=0) and after 12 months of bottle ageing (t=1), to determine any changes in wine sensory profiles. At t=0, flavoured white wines exhibited enhanced fruit aromas and flavours, but differences in sensory profiles between control and flavoured wines were less apparent at t=1. Compared to the control wines, the impact of ageing on flavoured Shiraz wines was less obvious, such that sensory differences were still apparent between control and flavoured wines after bottle ageing.

The project provides the wine industry with information that might enable producers to better identify and meet the needs of their consumers, subject to appropriate legislative change.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Yaelle Saltman Date

Dedications

I dedicate this thesis to the loving memory of my dad, (Professor) Michael Saltman, who passed away peacefully on October 26th 2016. Dad, it is a great privilege to dedicate my thesis in your honour. I have been dreaming of this moment for a very long time and I know that wherever you are, you are looking down right now and you are very proud.

I would also like to dedicate this thesis to my beautiful daughter. Noa, this thesis is dedicated to you, so you believe that you can do anything you set your mind to. Nothing will stop you achieving your goals, use that wonderful energy of yours to your advantage and you will fulfil all your dreams.

Acknowledgements

This doctoral thesis would not have been possible without the help of so many people. It is a great pleasure to express my heartfelt thanks and gratitude to everyone who has stood by me throughout this wonderful journey.

I would like to convey my sincere appreciation to my team of supervisors. To my Principal Supervisor, Associate Professor Sue Bastian, thank you for helping me turn my adventurous idea into sound scientific research. Your guidance and support, wisdom and expertise have helped see this research through to completion. Thanks also to Dr. Trent Johnson for your dedication and vast knowledge which you were always happy to share with me. Thank you Dr. Renata Ristic for our beautiful friendship and your professional and moral support. I owe a deep sense of gratitude to Associate Professor Kerry Wilkinson for your devotion, unlimited patience and timely advice. You are a great inspiration, as a scientist and as a person. I can't thank you all enough!

I would like to take this opportunity to thank Leslie Norris, who travelled to Australia to share her knowledge and expertise. Leslie, it was a great pleasure. And to Dr. Julie Culbert, thank you Jules, for the long hours you've contributed to this research.

I gratefully acknowledge the financial contribution of many industry partners: The University of Adelaide and Wine Australia for supporting my research, and for providing the opportunity to explore novel and exciting avenues in wine science. I would like to thank Treasury Wine Estates, Pernod Ricard, and Casella Wines, for your generous donation of wines; FlavorSense and The Product Makers for the provision of flavour additives.

A very special thank you goes out to my colleagues and friends, who helped me in so many ways, from technical support to their involvement as sensory panelists, but above all, I wish to thank you for lifting my spirits when they were lower and motivating me to keep going. To Vered, Anna, Mara, Jackie, Tony, Jo, Sijing, Liz, Kate, Lieke, Lukas, Jun, Shanna, Shira and Simon, thank you guys. I owe you a beer and my everlasting gratitude.

Finally, I wish to thank my family who are dearest and closest to my heart; my mum, Irit Saltman, and my brother, Amnon Saltman, for your unconditional love, support and encouragement; and my beautiful children, Noa and Adam, who are a source of such great happiness and joy.

Chapter 1. Introduction

The Australian wine industry is renowned for the quality and innovation of their wines and is one of the top ten producing countries in the world (Aylward 2006). From the mid-1990's until 2007 the Australian wine industry lead the export charge in the global market in what was considered the longest boom in its history; but since then countries such as New Zealand, Chile, Argentina and South Africa, who produce wines of similar price and quality have increased export growth and are enjoying international success (Anderson 2004; Anderson & Nelgen 2011). This has compelled the Australian wine industry to explore a range of new methods to improve wine quality so as to regain a competitive edge (Cox 2009). At the same time, the domestic market has also experienced a shift; consumers have become more knowledgeable and involved with wine (Wittwer & Rothfield 2005; Johnson & Bastian 2007), some consumers seek healthier wine choices (Thach 2004) or wines lower in alcohol content (Saliba, Ovington & Moran 2013), whereas others prefer wines produced in an environmentally sustainable manner, or wines made according to biodynamic or organic practices (Barber, Taylor & Deale 2010; Mueller & Remaud 2010). Furthermore, a new generation of wine drinkers, the Millennials, have recently joined the wine market, yet there is very little knowledge of their consumption behaviour or attitudes towards wine (Teagle, Mueller & Lockshin 2010). Collectively, these factors have influenced the quality and style of wines sought by Australian consumers, but few studies have explored the market's needs (Lattey, et al. 2007; Lattey, Bramley & Francis 2010; Bruwer, Saliba & Miller 2011).

The wine industry tends to invest in initiatives that educate wine consumers in the appreciation of existing wine styles rather than ascertaining the style of wines that consumers actually prefer drinking (Lesschaeve, Norris & Lee 2002; van Kleef, van Trijp & Luning 2005; Smith 2011). Decision making with regards to production is largely the responsibility of winemakers (Lattey, Bramley & Francis 2010) who also determine quality (Bisson et al. 2002), in what is a classic example of product concept versus marketing concept (Sharp 1991; Kotler et al. 2015). For example, Smith (2011) outlined the gradual shift from sweeter wine styles in favour of dry wines, which according to Smith was industry driven rather than consumer driven. Consumers had little choice but to accept changes in wine styles, alternatively they could turn to beverages such as alcopops or sweet wines, but this often left consumers dissatisfied and feeling uncultured (Bisson et al. 2002). Smith's findings reinforced earlier work that concluded trends towards dry wine styles were based on the industry assumption that increased consumer wine experience (or involvement) would increase preference for dry wines (Gluckman 1990; Spawton 1991). However to date, this hypothesis has not been supported by published empirical data.

In contrast to the wine industry, many other food and beverage industries have long recognised that in better meeting their consumers' needs and/or marketing their products effectively, they can improve success and profitability in the marketplace (McEwan 1996; Costa & Jongen 2006; Costell, Tárrega & Bayarri 2010). Food and beverage companies regularly seek feedback from consumers at various stages of product development, using different methods of qualitative and quantitative testing (MacFie 2007; Resurreccion 2007). Targeted consumer groups are recruited to provide insight into flavour and taste preferences, their acceptance of novel concepts or ideas, and the extent to which products' meet their sensory and/or quality expectations (Cardello 1994). Industry uses consumer responses to inform product development, as well as marketing strategies (Bayarri et al. 2012; Moskowitz, Beckley & Resurreccion 2012), particularly when introducing a novel product to the marketplace (Kwak et al. 2013).

Many variables can influence the acceptance, enjoyment and quality perception of different foods and beverages but it has been argued that along with price, sensory perception plays the most important role in determining consumers' decision making (Costell, Tárrega & Bayarri 2010; Bayarri et al. 2011). Current efforts in wine research that aim to enhance wine quality through modifications of aroma and flavour, are limited by the strict regulation of additives within the wine industry. Studies tend to focus on aroma and flavour manipulation that can be achieved by various winemaking techniques including the use of different yeast strains (Swiegers, Chambers & Pretorius 2005; Swiegers, Jan et al. 2007; Torrens et al. 2008), or malolactic bacteria (Bartowsky 2005), together with modifications to viticultural management practices (Jackson & Lombard 1993). Other food and beverage manufacturers make use of the wide range of food additives to improve the sensory properties of their products so as to better meet consumer expectations (Saltmarsh & Barlow 2013).

1.1 Food additives

The term “food additive” encompasses a range of substances permitted for use in food and beverage manufacturing to satisfy a range of consumer needs and expectations . This includes additives to improve appearance, (e.g. flavourings and colourings), to extend shelf-life (e.g. preservatives), to aid production (e.g. clarifying agents) or to impart health benefits (e.g. nutrients) (Branen et al. 2001).

Most countries have systems in place to regulate approved food additives; for example the Codex Alimentarius (International Food Safety Standards body), the Food and Drug Administration of the United States (FDA), or the European Food Safety Authority (EFSA) (Carocho, Morales & Ferreira 2015). The EU uses a numbering system prefixed by the letter “E” to designate the presence of additives on product labels (Saltmarsh & Barlow 2013). In Australia and New Zealand, food and beverage manufacturers, including the wine industry, must comply with a list of permitted substances comprising food additives, vitamins, minerals and processing aids that can be added during manufacturing, specified by the Australian and New Zealand Food Standards Code (Food Standard Australia New Zealand 2011). The code also governs labelling requirements, directions for use and storage, and the definitions of food additives as shown in Table 1.

Table 1. Definitions of food additives, flavour enhancers and flavourings

Food additives	Substance not normally consumed as a food in itself and not normally used as an ingredient of food, but which is intentionally added to a food to achieve one or more technological functions specified in schedule 5 (refer to appendix 1).
Flavour enhancer/modifier	Enhances the existing taste and/or odour of food.
Flavourings	Intense preparations which are added to foods to impart taste and/or odour; which are used in small amounts and are not intended to be consumed alone, but do not include herbs, spices and substances which have an exclusively sweet, sour or salt taste.

Definitions sourced from Food Standard Australia New Zealand 2011, standard 1.3.1.

1.2 Flavourings (flavour additives)

A flavouring is a chemical substance that affords flavour properties following addition to foods and beverages, or that compliments, magnifies and/or modifies existing flavours to deliver a pleasurable and satisfactory experience for consumers (Baines & Seal 2012).

The term "flavouring" refers to a single chemical with flavour properties (e.g. ethyl vanillin), however "flavourings" can also refer to mixtures of substances, flavour precursors and smoke preparations which can also be used to modify the flavour of food (Saltmarsh & Barlow 2013). There are more than 1,700 natural and synthetic (also known as artificial) flavourings available commercially (Carocho et al. 2014). The terms "natural" and "synthetic" refer to the process by which flavourings are manufactured, for example natural flavourings can be prepared from fruit extracts whereas artificial flavourings through chemical, enzyme or microbiological synthesis (Carocho, Morales & Ferreira 2015). Definitions for natural and artificial flavourings are presented in Table 2.

Table 2. Definitions of natural, nature identical and artificial flavourings

Natural flavourings	Plant and animal derived through enzymatic or microbiological procedures. For example vanilla flavourings from vanilla pods
Nature identical flavourings	Plant and animal derived flavourings prepared via chemical synthesis or isolation. These are chemically identical to natural flavourings but have been extracted using chemical methods. Vanilla extract could either be derived from vanilla pods (natural flavourings) or in the case of nature identical flavourings, the vanilla extract could be produced chemically from the plant material lignin.
Artificial (synthetic) flavourings	Chemical synthesis of materials other than plant or animal. For example the production of ethyl vanillin flavourings which has not been identified in nature.

Definitions are sourced from Siegwart (1993).

According to Longo & Sanromán (2006), flavourings represent a quarter of the total market for food additives, but when it comes to the origin of flavourings most, if not all, consumers prefer natural flavour additives rather than artificial flavourings (Senker 1990; Rozin et al. 2004; Bruhn 2007). Consumers are thought to perceive natural flavourings as healthier despite the fact that artificial additives don't pose any greater health risk compared to natural additives (Carocho et al. 2014). Natural additives are typically more expensive than artificial substances (Carocho, Morales & Ferreira 2015). It has been suggested that a general lack of knowledge and awareness concerning the origin of food additives leads consumers to prefer natural additives rather than artificial additives (Shim et al. 2011).

1.3 Wine and wine products

Wine is a complex matrix that comprises hundreds of volatile compounds derived from grapes, the fermentation process and ageing that influence aroma and flavour (Fischer 2007; King et al. 2010; Rapp & Mandery 1986). The addition of flavourings to compliment, enhance or modify existing wine aroma would contravene the legal definition of wine (Table 3).

Table 3. Definition of wine and wine products

Wines	Wine means the product of the complete or partial fermentation of fresh grapes, or a mixture of that product and products derived solely from grapes.
Wine products	means a food containing no less than 700 mL/L of wine as defined in this (Standard 2.7.4 p, 1), which has been formulated, processed, modified or mixed with other foods such that it is not wine (Standard 2.7.4. p, 2 Food Standards Australia and New Zealand).
Fruit Flavoured wines	If fruits other than grapes are added to grape wine, that product meets the definition of a wine product, provided it remains at least 70% grape (example of a wine product).

Definitions are sourced from Food Standard Australia and New Zealand, standard 1.3.1.

Products based on wine are routinely infused with various fruit, herbs and flavour additives, for example Sangria is a wine base containing sweeteners (e.g. honey or sugar), brandy and fruits; while Vermouth is a fortified wine flavoured with aromatic herbs and spices including cardamom, cinnamon, marjoram, and chamomile (Arn 1990).

In Australia, flavourings are used in the production of beverages classified as “wine products”. Examples include; Southcorp’s strawberry flavoured Killawarra Dusk and Hardy’s Omni Citrus which were specifically designed to target novice wine consumers (Carter 2006).

1.3.1 Wine additives

The Australia and New Zealand Food Standards Code is a complex system, and the number of permissible additives varies widely across different product categories. For example, for confectioneries and sauces the list of additives permitted in the final product exceeds 100. In contrast, the wine industry is only permitted to use half this number of additives during winemaking (i.e. ∼50 additives) (Table 4). Consequently, winemakers have fewer opportunities to modify wine composition and sensory properties. Common wine additives in Australian winemaking include tartaric acid to adjust acidity, grape-derived juice concentrates to adjust sweetness, cultured yeasts to facilitate fermentation, fining agents (e.g. Bentonite and egg white), preservatives (including SO_2 which assists in preventing oxidation and spoilage), tannins and oak. The Food Standards Australia New Zealand lists permit additives, which are generally classified either as "additives" or "processing aids" (Table 4). Processing aids are defined as "another set of food additives that may be added during manufacture but which do not perform a technological function in the final food" (Food Standard Australia New Zealand 2011).

Table 4. Additives permitted for use in Australian winemaking

Additives	Processing aids
Ascorbic acid	Activated carbon
Carbon dioxide	Agar
Citric acid	Alginates, calcium and potassium salts
Erythorbic acid	Ammonium phosphates
Grape juice including concentrated grape juice	Argon
Grape skin extract	Bentonite
Gum Arabic	Calcium carbonate
Lactic acid	Calcium tartrate
Malic acid	Carbon dioxide
Metatartaric acid	Cellulose
Mistelle	Chitosan sourced from Aspergillus niger
Potassium sorbate	Collagen
Potassium sulphites	Copper sulphate
Sodium carboxymethylcellulose	Cultures of microorganisms
Sorbic acid	Cupric citrate
Sulphur dioxide	Dimethyl dicarbonate
Tannins	Dimethylpolysiloxane
Tartaric acid	Egg white
Yeast mannoproteins	Enzymes
	Gelatine
	Hydrogen peroxide
	Ion exchange resins
	Isinglass
	Lysozyme
	Milk and milk products
	Nitrogen
	Oak
	Oxygen
	Perlite
	Phytates
	Plant proteins
	Polyvinyl polypyrrolidone
	Potassium carbonate
	Potassium ferrocyanide
	Potassium hydrogen carbonate
	Potassium hydrogen tartrate
	Silicon dioxide
	Thiamine chloride
	Thiamine hydrchloride

The list of additives is sourced from Food Standard Australia New Zealand 2011, Standard 4.5.1.

Additives and processing aids are used to stabilise, protect wines from oxidation and ultimately maintain the quality of wine (Bird 2000). To enhance complexity, wines may spend a period of time in oak barrels during which oak derived aromas of vanilla, caramel and sweet spices are imparted (Spillman, Sefton & Gawel 2004), however, many winemakers are increasingly using oak alternatives (i.e. staves, chips, powder) to impart oak characters to wines in a more time- and cost-efficient manner (Crump et al. 2014). According to Carey (2009) a wine which was appropriately treated with oak chips (classified as a processing aid as per Table 4) is likely to demonstrate oak aroma descriptors such as; spicy and clove (eugenol); smokey characters (guaiacol); fresh oak and coconut (*cis*-oak lactone); butterscotch, caramel and almond (furfural); and vanilla (vanillin). Oak chips not only contribute to the complexity and quality of wines but, according to Crump et al. (2014), the majority of Australian wine consumers accept the use of alternative oak treatments, thus is it an overall triumph for both consumers and industry. Flavour additives on the other hand, which can perform a similar function as oak alternatives, are regarded as fraudulent.

1.4 Adulteration, spiking and authentication of wine

Each wine producing country has its own laws and legislation concerning winemaking processes. Just as the definition of “wine” varies slightly between Australia, USA, the EU and South Africa, so does the legislation involving the use of additives together with labelling requirements. Despite variation between countries, it is generally accepted worldwide that mishandling of additives, and misinforming consumers, are considered fraudulent practices and constitutes wine adulteration (Holmberg 2010). In food, the term economically motivated adulteration (EMA) is used to describe the intentional adulteration of food for financial advantage.

The intentional adulteration of wine for fiscal benefit is not a new practice and has occurred since ancient times (Dordevic et al. 2013). The media, however, has brought incidents of adulteration to light. In recent years there has been an increasing number of reports describing producers’ misuse of additives and attempts at quality deceptions (Phillips 2000). Prominent examples include: the “antifreeze wine scandal” which occurred in Austria in 1985, and involved approximately 70 wine producers being caught adding diethylene glycol to sweeten late harvest wines (Holmberg 2010; Kester 2010), with severe consequences to the Austrian wine industry’s reputation. In 2004, two South African winemakers purportedly added natural vegetable extracts to Sauvignon Blanc wines to enhance the vegetal characters (e.g. green capsicum) typical of this variety (Lechmere 2004). In Australia, allegations have been made against wineries concerning the illegal use of silver nitrate to remove sulphurous “off” odours, and the addition of red tannin colouring to transform white wine into red wine (Stone 2001).

Breaches such as these suggest that some winemakers perceive the financial benefits associated with using prohibited additives outweigh the risk of detection. This indicates that there is scope to investigate potential benefits of using flavour additives to improve wine quality, not only from a consumer perspective, but also from an industry perspective, in terms of addressing a growing number of competing wineries worldwide and challenging environmental conditions. The use of flavourings as a corrective method is attractive for the wine industry, because the application is simple and additions could be made during various stages of production.

1.5 Research Objectives

1.5.1 Objective 1

To determine Australian wine consumers’ acceptance of and attitudes toward the use of additives in wine and food production and to explore consumers’ preferred flavours for white and red wines.

Flavour additives are commonly used in food and beverage production to enhance aroma and flavour or mitigate undesirable attributes. Thus an assumption is made that this will also apply to wines, however it is not clear to what extent Australian consumers would accept the use of flavourings in winemaking and whether consumers’ attitudes towards flavourings differs to that of existing wine additives (Chapter 2).

1.5.2 Objective 2

To explore the impact of natural flavour additives on the sensory perception and consumer liking of Chardonnay and Shiraz wines.

This Objective aims to explore how the addition of natural flavour additives might influence the sensory perception of the flavoured wines. Would wine consumers prefer the flavoured wines over the control wine (without additives) (Chapter 3)?

1.5.3 Objective 3

To investigate the impact of bottle ageing on the sensory and chemical composition of Chardonnay and Shiraz wines with added flavour additives.

The combination of sensory and chemical data will provide insight on the possible changes that may occur after bottle ageing (Chapter 4).

Note: This study aimed to explore the possibility of adding flavourings to improve palatability of 'wines', in the same way that other winemaking additives are already used for corrective purposes (Lesschaeve & Noble 2005). This is not a product development research project aiming to design 'wine products' with added flavourings.

1.6 Methodology

To address the research objectives, a series of experiments was undertaken involving consumer research, sensory profiling and compositional analysis methods as outlined below.

1.6.1 Consumer research

A consumers' choice of wine is often more complicated than their choice of products in other fast moving consumer goods (Lockshin & Hall 2003). In Australia, there are thousands of wineries and brands, dozens of grape varieties, regions, labels, wine styles, and a range of prices to choose from, which influences the decision making process and purchasing behaviour (Lockshin & Corsi 2012). Wine is evaluated through its extrinsic and intrinsic attributes (Lockshin & Hall 2003; Charters & Pettigrew 2005); extrinsic attributes include; price, brand (Lockshin et al. 2006; Mueller et al. 2010), and perceived quality (Cox 2009), whereas intrinsic attributes include grape variety, grape origin, wine style (McCutcheon, Bruwer & Li 2009) and sensory characteristics (Keown & Casey 1995). Whilst it is common for wine producers to improve the perception of quality though labelling, branding and packaging (Mueller & Szolnoki 2010), some argue that sensory characteristics are the biggest contributors to consumer's perceived quality of wine (Charters & Pettigrew 2005), providing consumers can taste the wine prior to purchasing. Jaeger et al. (2009) later confirmed that taste was the most salient attribute in purchase intent in a sample of New Zealand wine consumers. Surprisingly, to date very few sensory based consumer studies have been conducted to explore consumer's flavour preferences (Bruwer, Saliba & Miller 2011). Thus, developing an understanding of consumers' sensory preferences in wine, is an area of research that should be further developed (Lesschaeve 2007).

Food industries have recognised the value in using sensory marketing strategies to identify drivers of consumer liking, using a combination of quantitative and qualitative methods (Raz et al. 2008). It has become increasingly popular to integrate qualitative research (e.g. interviews and focus groups) with qualitative methods (survey) conveying a sense of rigour to the research (Bryman 2006).

To address Objective 1, a combination of consumer research methods was used:

- A survey (1000 Australian consumers) was administered to explore consumers' acceptance of and attitudes towards the use of additives in wine. Consumers were also asked to provide their preferred flavours in white or red wines (Chapter 2).
- Focus group tasting panels were conducted, involving approximately 50 participants, to provide feedback on prototype flavoured wines (Chapter 2).
- Consumer tastings (approximately 200 consumers) were held to provide hedonic feedback on the level of liking of the flavoured wines vs the control (Chapter 2).

1.6.2 Sensory profiling

Descriptive analysis (DA) is a method used by sensory scientists to generate a comprehensive profile of the sensory properties of a product, and involves quantification of the intensity of a range of attributes detected by a trained panel of judges (Murray, Delahunty & Baxter 2001; Meilgaard, Carr & Civille 2006). Generally DA involves two distinct phases: training and formal wine assessment. Throughout the training phase several 1-2 hour sessions are held until judges develop a concise list of terms that describe the sensory differences between the wines and become familiarized with the samples. During the evaluation phase, judges rate the intensity of the attributes from the developed list they generated. Evaluation is normally carried out in isolated booths in controlled conditions (e.g. temperature, ventilation and lighting). This generic descriptive analysis (Lawless & Heymann 1999), may vary according to specific research objectives (Murray, Delahunty & Baxter 2001) and may include a variation of techniques such as quantitative descriptive analysis (Stone et al. 1974); or free choice profiling (Langron 1983).

To address the second objective in this research, which is to explore the impact of natural flavour additives on the sensory perception of Chardonnay and Shiraz wines, two descriptive analysis panels were assembled for each variety (Chapter 3).

To investigate the impact of bottle ageing on the sensory profiles of the flavoured wines (Objective 3), subsequent descriptive analysis panels (for Chardonnay and Shiraz) were assembled to profile the wines 12 months after bottling.

1.6.3 Compositional analysis (GC-MS)

High resolution gas chromatography (GC) techniques and fast scan mass spectrometers (MS) is the analytical technique traditionally used for identifying trace amounts of volatile compounds in wines (Teranishi, Wick & Hornstein 2012). Numerous studies have employed GC-MS for qualitative and quantitative analysis. In this current study GC-MS was used to analyse the composition of flavourings and flavoured wines (Chapter 4).

1.7 Summary

Flavour additives are routinely used in the food and beverage industries to enhance aroma and flavour intensity of products and better meet consumers' needs. The assumption is made that the wine industry could potentially utilize flavour additives to improve wine quality when seasonal conditions are not ideal, and to enhance certain sensory attributes to meet the expectations and preferences of different consumer segments.

This research set out to explore Australian consumers' acceptance of and attitudes toward the use of additives in wine, specifically flavour additives, using an online survey. Based on the information provided by consumers (online survey) on preferred flavours in white and red wines, a range of flavour additives was used in lower quality commercial wines to enhance aromas and flavours, and examine if the addition of flavour additives (natural) had in fact resulted in wines that could be significantly distinguished (i.e., aroma, flavour, taste and mouthfeel) from the control wines, using DA panels. The following step would be to investigate if consumers liked the flavoured wines over the control wines, through consumer acceptance tests. The last study involved further examination of the wines after a year of bottle ageing, using DA panels and compositional analysis.

Chapter 2. Paper 1 – Australian wine consumers' acceptance of and attitudes toward the use of additives in wine and food production.

Over the last three decades, the Australian wine industry has gained a reputation for producing quality wines and utilising innovative techniques to improve quality. Furthermore, the industry is gradually shifting to produce consumer driven wines rather than reserving quality judgements for winemakers. Thus it is reasonable to suggest that prior to utilising novel techniques, consumer feedback is sought.

In this research, the use of flavour additives is suggested as an innovative approach for improving wine quality. Flavour additives, or flavourings, are routinely used in the manufacturing of food and beverage products to intensify aroma and flavour, and better meet consumer expectations. From an industry perspective, the potential for wines might be made more palatable with the addition of flavourings, especially in vintages where poor seasonal condition results in lower quality grapes, presents an attractive option. However, current legislation in Australia involving the production of wines does not permit the use of flavourings, and to date, studies have not investigated consumers' acceptance of flavour additives in wines.

This paper therefore reports a study into consumer attitudes toward the use of additives in wine and food production. An online survey of 1031 Australian wine consumers determined the acceptance of and attitudes toward the use of additives, in particular flavour additives, in wine and food products.

Statement of Authorship

Yaelle. Saltman, Trent E. Johnson, Kerry L. Wilkinson, Susan E.P. Bastian (2015).

Australian wine consumers' acceptance of and attitudes toward the use of additives in wine and food production. Internation Journal of Wine Research, 7: 83-92.

Yaelle Saltman

Designed and conducted consumer experiments (online survey), analysed and interpreted consumer data, drafted and revised manuscript. Overall contribution 80%.

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis.

Signed Date...8/11/2016....

Trent Johnson

Assisted in survey design, analysed and interpreted consumer data, assisted with revising the manuscript.

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis.

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Kerry Wilkinson

Assisted in survey design, analysed and interpreted consumer data, assisted with revising the manuscript.

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Assisted in survey design, analysed and interpreted consumer data, assisted with revising the manuscript.

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Signed Date.....7.11.16.......

International Journal of Wine Research

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ORIGINAL RESEARCH

Australian wine consumers' acceptance of and attitudes toward the use of additives in wine and food production

This article was published in the following Dove Press journal:
International Journal of Wine Research
2 November 2015
Number of times this article has been viewed

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Abstract: Additives are routinely used in food and wine production to enhance product quality and/or prevent spoilage. Compared with other industries, the wine industry is only permitted to use a limited number of additives. Whereas flavor additives are often used to intensify the aroma and flavor of foods and beverages, the addition of flavorings to wine contravenes the legal definition of wine. Given the current legislation, it is perhaps not surprising that the potential use of food additives in wine production has not been explored. This study therefore investigated Australian wine consumers' acceptance of and attitudes toward the use of additives in food and wine production. Consumers (n=1,031) were segmented based on their self-reported wine knowledge (ie, subjective knowledge). Using these ratings, low (n=271), medium (n=528), and high (n=232) knowledge segments were identified. Consumers considered natural flavorings and colors, and additives associated with health benefits (eg, vitamins, minerals, and omega 3 fatty acids), to be acceptable food additives, irrespective of their level of wine knowledge. In contrast, the use of winemaking additives, even commonly used and legally permitted additives such as tartaric acid, preservatives, oak chips, and tannins, were considered far less acceptable, particularly, by less knowledgeable consumers. Surprisingly, natural flavorings were considered more acceptable than currently used winemaking additives. Consumers were therefore asked to identify the flavors they would most prefer in white and red wines. Fruit flavors featured prominently in consumer responses, eg, lemon and apple for white wines and blackcurrant and raspberry for red wines, but vanilla and/or chocolate, ie, attributes typically associated with oak maturation, were also suggested.

Keywords: wine quality, segmentation, natural flavors, artificial flavors, wine knowledge

Introduction

For centuries, additives have been used to extend shelf-life and enhance food flavor, eg, the addition of salt to preserve fish and meat, sugar to preserve fruit, vinegar to pickle vegetables, and herbs and spices to enhance flavor.[1,2] Today, food additives are widely used at different stages of food and beverage production for a range of purposes. The term "food additive" encompasses a range of permissible substances, including flavorings, colorings, texture modifiers, nutrients, and preservatives.[3] These additives are generally used in food and beverage production to: improve appearance (eg, flavorings, colorings); extend shelf-life (eg, preservatives); aid production (eg, clarifying agents); impart health benefits (eg, nutrients); and satisfy consumer expectations.[4,5]

The Australia New Zealand Food Standards Code (Code 1.3.1), which embodies food and beverage production, is a complex system, and the number of permissible additives varies widely across product categories. For example, for confectionaries

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Dovepress
http://dx.doi.org/10.2147/IJWR.S90802

and sauces, the list of permitted additives in the final product exceeds 100; in contrast, the wine industry is only permitted to use half this number of additives during winemaking (ie, ~50 additives). Consequently, winemakers have fewer opportunities with which to modify wine quality. In Australia, common wine additives include tartaric acid, grape-derived juice concentrates, cultured yeasts, fining agents, preservatives, grape-derived color extracts, tannins, and oak wood. The Food Standards Australia New Zealand[6] lists the permitted additives, which are generally classified either as "additives" or "processing aids". Flavor additives are not permitted in the production of wine, which is strictly (and legally) defined in Standard 2.7.4 as "the product of the complete or partial fermentation of fresh grapes, or a mixture of that product and products derived solely from grapes".[6] To date, wine consumers' acceptance and attitudes toward the additives used in wine production have not been established.[7]

Wine producers have not always conformed to the strict regulations prescribing the use of additives in winemaking. In some cases, wine producers have admitted to the use of unauthorized additives to improve wine quality.[8] The addition of prohibited substances to wine is known as adulteration or as fraud.[9] Breaches of this kind suggest that some winemakers find the financial benefits of enhancing wine quality irresistible. Around the world, several incidents involving mishandling of wine have featured in media headlines, including reports in which producers allegedly adulterated wines by adding prohibited substances.[8] The 1985 Austrian "antifreeze wine scandal" involved the addition of diethylene glycol to late harvest, sweet style wines to enhance sweetness.[9,10] More recently, a South African winemaker supposedly added natural vegetable extracts to Sauvignon Blanc to enhance the vegetal character of the wine.[11] Adulteration was also discovered in Australia when in 2000, an Australian winery was investigated following the alleged addition of silver nitrate to remedy sulfurous off-odors; with severe consequences for the winery concerned.[12]

Currently, flavor additives are only permitted in the production of "wine products", ie, "food containing no less than 700 mL/L of wine which has been formulated, processed, modified, or mixed with other foods such that it is not wine".[6] Wine products are generally targeted toward prospective wine consumers and/or wine consumers who do not drink often;[13] Rosemount winery's "botanical" range, for example, came out with a range which consists of wine infused with fruit. However, there may be merit in the use of flavor additives as a technical solution for improving low-quality wine; pending consumer acceptance of wines made with flavor additives.

Other food and beverage industries have long recognized the success or failure of a product in the market depends on the factors driving consumer acceptability;[14,15] yet surprisingly, relative to food, limited research has been undertaken to investigate the factors driving consumer acceptance of wines. Wine knowledge, prior consumption, wine style, grape variety, occasion, and price strongly influence wine selection and purchasing behavior,[16–19] but to date, few studies have considered consumers' acceptance of and attitudes toward the use of additives in wine and food production.

Consumer populations contain discreet segments of individuals who share common behaviors with respect to given product categories. By identifying and understanding individual consumer segments, industry can tailor products to specifically meet their respective needs; thus, segmentation serves as an important tool. Wine knowledge is a variable that measures consumers' understanding of wine as a product, and can be measured either objectively or subjectively.[20] Objective knowledge is measured using a series of questions that evaluate an individual's familiarity with a wine product[21] and is defined as "accurate information about the product class stored in long term memory".[22] Subjective knowledge is a self-reported measure of individuals' perceptions of how much they know about a product class.[23] Although a limitation of subjective knowledge is the possible discrepancy between what people think they know and what they actually know, previous research on wine knowledge[17] concluded the two knowledge scales are highly correlated. Therefore, the subjective knowledge scale has been widely used in the wine marketing literature, as the basis for segmentation of large consumer populations.[20,24,25] Wine knowledge has also been found to greatly influence consumers' flavor preferences,[20] wine involvement,[26] and purchasing behavior.[27] However, it is not known how consumers' wine knowledge affects their perception of the use of additives in food and whether this differs to their opinions about additives in wine.

Additives, in particular flavors, are commonly used in foods and beverages to enhance quality, so it is reasonable to make the assumption that this would also be true in wines. The objectives of this study were to determine consumers' acceptance of the use of flavor additives during wine production. We analyze consumer perceptions of additives including natural and artificial flavors in wine and food and determine if consumers' wine knowledge assessed by the subjective knowledge scale[23] will influence their acceptance, opinions, and convictions about additives used in wine and food production.

Materials and methods

Consumer sample

Wine consumers (n=1,031) were recruited nationally via a market research company (PureProfile, Sydney, Australia) and social media (including Facebook and electronic newsletters). Inclusion criteria required respondents to be of legal drinking age (ie, ≥18 years of age), regular wine drinkers (ie, wine consumption ≥ once per month), and residents of Australia. Demographic and alcohol and wine consumption characteristics of participants are reported in Table 1.

Questionnaire

An online questionnaire administered via SurveyMonkey™ (Palo Alto, CA, USA; www.surveymonkey.com) was developed to ascertain Australian wine consumers' opinions and acceptance of the use of additives in food and wine. The questionnaire comprised five sections. The first section contained demographic questions relating to sex, age, education, and household income, as well as alcohol and wine consumption behavior (Table 1). The second section investigated consumers' opinions about the use of various additives in wine and food (Tables 2 and 3). Section three then asked consumers to rate their acceptance of a range of additives used in wine and food production (Tables 4 and 5). Respondents were asked to indicate their level of agreement with a series of statements using a 9-point category scale, where 1= strongly disagree, 5= neither agree nor disagree, and 9= strongly agree. These statements were based on questions used in previous studies investigating consumer acceptance of additives used in food and beverage industries.[28,29] In the fourth section, respondents

Table 1 Demographic and consumption behavior of Australian wine consumers and low, medium, and high wine knowledge segments

Demographic and consumption behavior	Total sample (n=1,031)	Wine knowledge segments		
		Low (n=271, 26.3%)	Medium (n=528, 51.2%)	High (n=232, 22.5%)
Sex				
Male	44.9	36.6	45.0	54.3
Female	55.1	63.4	55.0	45.7
Age (years)				
18–24	11.8	14.6	12.3	7.4
25–34	22.2	18.3	22.2	26.6
35–44	19.4	20.1	18.4	20.9
45–65	34.7	31.3	34.5	39.1
65+	11.9	15.7	12.5	6.1
Education				
Nontertiary education	48.1	54.9	51.1	33.5
Tertiary education	51.9	45.1	48.9	66.5
Household income				
<AUD $50,000	28.5	34.0	30.4	17.9
AUD $50,001–100,000	36.7	39.2	35.4	36.5
AUD $100,001–200,000	29.5	23.7	29.6	36.1
>AUD $200,000	5.3	3.0	4.6	9.6
Consumption behavior				
Consumption of alcoholic beverages				
Beer		21.3^{ab}	21.4^{a}	17.9^{b}
Wine		49.9^{b}	52.0^{b}	65.1^{a}
Spirits		14.1^{a}	13.5^{a}	8.8^{b}
Premixes		5.0^{a}	3.9^{ab}	1.1^{b}
Cocktails		3.7	3.3	2.4
Cider		4.7	4.8	4.0
Other		1.2	1.1	0.5
Consumption of different wine styles				
Sparkling wine		16.8^{a}	14.7^{a}	11.6^{b}
Rosé wine		5.2	6.2	5.0
Light-bodied white wine		27.4^{a}	23.7^{b}	20.3^{b}
Full-bodied white wine		12.1	10.8	11.5
Red wine		31.4^{c}	37.3^{b}	45.0^{a}
Dessert wine		3.4^{ab}	4.3^{a}	2.8^{b}
Fortified wine		3.7	3.1	3.8

Notes: Data are presented as percentages. Different superscript letters within a row indicate significant differences between knowledge segments ($P \leq 0.05$, one-way ANOVA, Fisher's LSD).
Abbreviations: LSD, least significant difference; ANOVA, analysis of variance.

Table 2 Australian consumers' opinions on the use of additives in wine production

Wine additive statements	**Wine knowledge segments**			
	Low (n=271, 26.3%)	**Medium (n=528, 51.2%)**	**High (n=232, 22.5%)**	***P*-value**
A wine label that lists "blackcurrant aroma" indicates the wine contains blackcurrant fruit	3.5^a	3.5^a	1.8^b	0.0001
Wines are typically fermented with the addition of yeast*	5.3^a	5.6^a	6.8^b	0.0001
In Australia, you are permitted to add color (extracted from grapes) to wine to improve appearance*	5.9^b	5.8^b	6.3^a	0.0001
Wines are always made from grapes*	4.5	4.6	4.7	0.776
Winemakers are allowed to add oak chips to wines, instead of maturing the wine in oak barrels*	5.4^c	5.7^b	7.0^a	0.0001
During winemaking, products containing milk can be added to the wines*	5.1^b	5.3^b	6.6^a	0.0001
Pomegranate wine is a wine	5.7	5.6	5.7	0.710
During winemaking, products containing fish can be added to the wines*	4.3^c	4.7^b	5.8^a	0.0001
If a wine label states "the wine displays hints of vanilla", this means vanilla has been added to the wine	3.9^a	3.8^a	1.9^b	0.0001
There is a difference between "wine" and "wine product"*	6.9^b	6.5^c	7.4^a	0.0001
During winemaking, products containing eggs can be added to the wines*	5.0^c	5.4^b	7.1^a	0.0001
Wines can be fermented with wild yeast (naturally found on grapes)*	6.1^b	6.3^b	7.7^a	0.0001
Organic wines are free of any food additives, including preservatives	4.9^a	5.0^a	4.2^b	0.0001

Notes: Data are means, where 1= strongly disagree, 5= neither agree nor disagree, and 9= strongly agree. Different superscript letters within a row indicate significant differences between knowledge segments ($P \leq 0.05$, one-way ANOVA, Fisher's LSD, $df = 2$); *indicates that the statement is true.
Abbreviations: LSD, least significant difference; ANOVA, analysis of variance.

were asked to rate their subjective wine knowledge,[23] and several other consumer behaviors not reported in this paper. The final section comprised an optional, open-ended question asking consumers "If you could create a wine with your favorite flavors, what would you make?"

Preliminary screening of the questionnaire was undertaken by 30 staff and students from the University of Adelaide's Wine Science group, to ensure the clarity of survey questions.

Segmentation of consumers according to wine knowledge

Respondents were asked to rate their level of agreement (9-point scale) to the five statements of the subjective wine

Table 3 Australian consumers' opinions on the use of additives in food production

Food additive statements	**Wine knowledge segments**			
	Low (n=271, 26.3%)	**Medium (n=528, 51.2%)**	**High (n=232, 22.5%)**	***P*-value**
Food additives are represented by a numbering system	6.9^a	6.5^b	6.7^{ab}	0.006
Natural food additives are less harmful than artificial additives	6.3^a	6.1^a	5.6^b	0.0001
Preservatives are added to food products to increase shelf-life	7.8^a	7.1^b	7.5^a	0.0001
Organic products do not have additives in them	5.8^a	5.6^a	5.1^b	0.001
Food additives are added to products to disguise poor quality	5.2^a	5.2^a	4.7^b	0.017
Preservatives are added to food to reduce spoilage	7.5^a	6.9^b	7.6^a	0.0001
Food additives are harmful to health	5.9^a	5.7^a	5.1^b	0.0001
Preservatives in food are harmful to health	5.8^a	5.7^a	5.1^b	0.0001

Notes: Data are means, where 1= strongly disagree, 5= neither agree nor disagree, and 9= strongly agree. Different superscript letters within a row indicate significant differences between knowledge segments ($P \leq 0.05$, one-way ANOVA, Fisher's LSD, $df = 2$).
Abbreviations: LSD, least significant difference; ANOVA, analysis of variance.

Table 4 Australian consumers' acceptance of additives in wine

Wine additive	Wine knowledge segments			
	Low (n=271, 26.3%)	**Medium (n=528, 51.2%)**	**High (n=232, 22.5%)**	***P*-value**
Natural flavoring	6.4^{a}	6.1^{a}	5.4^{b}	0.0001
Artificial flavoring	3.1^{a}	3.4^{a}	2.5^{b}	0.0001
Preservatives	4.3^{b}	4.6^{b}	5.3^{a}	0.0001
Acid	4.3^{c}	4.7^{b}	5.3^{a}	0.0001
Oak chips	4.5^{c}	5.0^{b}	5.6^{a}	0.0001
Tannins	4.9^{b}	5.1^{b}	5.9^{a}	0.0001
Natural color	6.4^{a}	6.0^{b}	5.6^{c}	0.0001
Artificial color	3.3^{b}	3.6^{a}	2.6^{c}	0.0001
Grape sugar extracts	5.9	5.7	5.8	0.148
Gelatin	4.2	4.4	4.2	0.225
Vitamins	6.0^{a}	5.7^{ab}	5.3^{b}	0.001

Notes: Data are means, where 1= highly unacceptable, 5= neither acceptable nor unacceptable, and 9= highly acceptable. Different superscript letters within a row indicate significant differences between knowledge segments ($P \leq 0.05$, one-way ANOVA, Fisher's LSD, $df = 2$).
Abbreviations: LSD, least significant difference; ANOVA, analysis of variance.

knowledge scale,[23] where 1= strongly disagree, 5= neither agree nor disagree, and 9= strongly agree. The scale included both positively and negatively worded statements. The negatively worded statements were subsequently reversed, the scores summed and converted to a percentage. Then, following the protocol outlined by Quester and Smart,[30] the 25th and 75th percentiles were identified and used as the cutoff points for the low and high knowledge segments, respectively, thereby creating three knowledge segments.

Statistical analysis

SPSS 20 (IBM Corporation, Armonk, NY, USA) was used to perform Cronbach's alpha, Kaiser–Meyer–Olkin value, Bartlett's test of sphericity, factor analysis, and Pearson correlation tests. XLSTAT (version 2011.5.01; Addinsoft, Paris, France) was used to perform one-way analysis of variance (ANOVA) where mean comparisons were performed by Fisher's least significant difference (LSD) post hoc test at $P < 0.05$.

Results and discussion

Consumer demographics, segmentation, and consumption behavior

The questionnaire was completed by 1,031 Australian wine consumers, who were recruited through a marketing research company and social media. The data from the two sources were analyzed to see if there were differences in the respective demographic profiles. As no differences were found (data not shown), the two datasets were combined. Participants were evenly distributed across the different age groups, with slightly higher participation by females (55.1%) than males (44.9%) (Table 1). Approximately half

Table 5 Australian consumers' acceptance of additives in food

Food additive	Wine knowledge segment			
	Low (n=271, 26.3%)	**Medium (n=528, 51.2%)**	**High (n=232, 22.5%)**	***P*-value**
Natural flavoring	6.7^{a}	6.4^{b}	6.3^{b}	0.024
Artificial flavoring	3.4^{ab}	3.6^{a}	3.1^{b}	0.015
Preservatives	4.4^{b}	4.5^{b}	4.9^{a}	0.004
Omega 3	7.3^{a}	7.0^{b}	7.1^{b}	0.004
Salt	4.7	4.9	4.8	0.389
Artificial sweeteners	3.8^{ab}	4.1^{a}	3.4^{b}	0.0001
Natural color	6.8^{a}	6.4^{b}	6.5^{ab}	0.007
Artificial color	3.6^{ab}	3.7^{a}	3.3^{b}	0.025
Monosodium glutamate	2.6	2.9	2.6	0.380
Minerals (eg, calcium, zinc)	6.9^{a}	6.4^{b}	6.4^{b}	0.0001
Thickeners	4.7	4.8	4.8	0.538
Folate	6.5^{a}	6.2^{b}	6.3^{ab}	0.047
Vitamins	7.5^{a}	7.0^{b}	7.1^{b}	0.0001

Notes: Data are means, where 1= highly unacceptable, 5= neither acceptable nor unacceptable, and 9= highly acceptable. Different superscript letters within a row indicate significant differences between knowledge segments ($P \leq 0.05$, one-way ANOVA, Fisher's LSD, $df = 2$).
Abbreviations: LSD, least significant difference; ANOVA, analysis of variance.

(51.3%) the participants held tertiary qualifications which were consistent with socio-demographic data reported for Australian wine consumers.[31] Participants' household incomes were slightly higher than the Australian median of approximately AUD$65,000,[32] which can be attributed to the more qualified consumer sample.

Respondents were segmented using the subjective knowledge scale.[23] The reliability and unidimensionality of the subjective knowledge scale was analyzed. The data revealed a Cronbach's alpha of 0.87, the correlation matrix returned all values in excess of 0.3,[33] the Kaiser–Meyer–Olkin value was 0.82, and Bartlett's test of sphericity was significant ($P<0.001$). Subsequent factor analysis revealed a unidimensional scale which was used to segment the sample. The lowest quartile (n=271, 26.3%) scored less than 42.2% and the highest quartile (n=232, 22.5%) scored greater than 66.7%. The remaining 528 respondents (51.2%) became the medium knowledge segment.

The demographics for each knowledge segment (Table 1) revealed that the high knowledge segment comprised a higher proportion of male consumers (54.3%) than the low (36.6%) and medium (45.0%) knowledge segments (Table 1). Only 13.5% of the high knowledge segment comprised consumers aged below 25 or above 65 years of age; with most consumers (ie, 86.5%) aged between 25 and 65 years. Highly knowledgeable consumers were more likely to hold tertiary qualifications and thus, the highest household incomes were reported for this segment. In contrast, the low knowledge segment comprised the highest proportion of female consumers (63.4%), with age distributions skewed in favor of younger (18–24 years) and older (>65 years) consumers (ie, 30.3%). Only 45% of low knowledge consumers held tertiary qualifications, which likely explains their comparatively lower average household income; ie, 73% of low knowledge consumers reported a household income of <AUD$100,000. Wine was the preferred alcoholic beverage for each knowledge segment, but the high knowledge segment consumed significantly more wine (65.1%) than the other segments and in particular, consumed significantly more red wine (45.0%) than low (31.4%) and medium (37.3%) knowledge segments, who instead consumed higher proportions of sparkling and light-bodied white wines.

Consumer attitudes toward the use of additives in wine and food

Australian winemakers are permitted to use approximately 50 different winemaking additives during production, none of which are flavor additives per se. However, labeling laws only specify that preservatives (eg, sulfur dioxide) and fish-, milk- and egg-derived additives must be reported on wine back labels, for health purposes.[6] Wine labels do not usually indicate the use of any other winemaking additives, so wine label content does not typically inform consumers regarding the use of additives in wine. The objectives of this study were to determine consumer acceptance of and attitudes toward winemaking additives. Consumers were therefore asked to indicate their agreement/disagreement to a series of statements related to the definitions of wine and wine products, winemaking practices, and the use of additives in wine (Table 2).

As expected, highly knowledgeable wine consumers generally had stronger convictions regarding winemaking practices; ie, they agreed that "Wines are typically fermented with the addition of yeast" (6.8/9), "Wines can be fermented with wild yeast" (7.7/9), "Winemakers are allowed to add oak chips to wines, instead of maturing the wine in oak barrels" (7.0/9), and that "During winemaking, products containing eggs can be added to the wines" (7.1/9). In contrast, low and medium knowledge segment responses to these statements were significantly lower, ie, ranging from 5.0 to 5.7, except for the "wild yeast" statement, for which responses ranged from 6.1 to 6.3. Responses close to 5.0, ie, "neither agree nor disagree", are also known as "midpoint" responses[34,35] and indicate neutrality or indifference, whereas "endpoint" responses, ie, responses situated away from 5.0, indicate greater conviction. As such, the high knowledge segment was less confident regarding the use of milk- and fish-derived products (6.6/9 and 5.8/9, respectively), whereas low and medium knowledge segment responses were again significantly lower at between 4.3 and 5.3. Irrespective of their level of wine knowledge, consumers were aware that wines exhibiting blackcurrant or vanilla aromas did not actually contain blackcurrant or vanilla; albeit the high knowledge segments were more strident in their responses (1.8 and 1.9/9) than the low and medium knowledge segments (3.5–3.9/9).

When it came to consumers' attitudes toward what constitutes wine, wine products and organic wine, even knowledgeable consumers' responses were less confident. There was no significant difference between wine knowledge segment responses to statements that "Wines are always made from grapes" (4.5–4.7/9) and "Pomegranate wine is a wine" (5.6–5.7/9). The high knowledge segment response to the statement "Organic wines are free of any food additives, including preservatives" was significantly lower (4.2/9) than that of low and medium knowledge segments (4.9–5.0/9), but all were considered "midpoint" responses. These results were in agreement with a previous study, which found approximately 50% of consumers were unsure of what constitutes a wine product, and as a consequence, these consumers negatively valued wine products.[36]

With regards to the use of additives in food (Table 3), consumers generally agreed that "Preservatives are added to food to increase shelf-life" (7.1–7.8/9) and "… to reduce spoilage" (6.9–7.6/9), in agreement with previous research.[37] Consumers also agreed that "Food additives are represented by a numbering system" (6.5–6.9/9) and "Natural food additives are less harmful than artificial additives" (5.6–6.3/9), but relatively neutral responses (ie, responses ranging from 4.7 to 5.9) were observed for other statements. While significant differences were observed between wine knowledge segment responses, these were not considered meaningful, because mean responses only varied by ≤0.8. These results indicated the wine consumers surveyed had similar opinions regarding the use of additives in food, regardless of their knowledge of wine.

Consumer acceptance of the use of additives in wine and food

Consumers were presented with a list of additives and then were asked to indicate their acceptance of each as a potential additive in wine (Table 4) or food production (Table 5). In the case of wine additives, this included both permitted additives, such as oak chips, tannins, and acid, and additives not currently permitted, such as artificial color, artificial flavoring, and vitamins. Low and medium knowledge segments were moderately accepting of the use of natural flavoring, natural color, and vitamins; with mean responses for these additives ranging from 5.7 to 6.4/9. This was surprising, given flavorings and vitamins are not permitted additives and only grape-derived color extracts qualify as legal winemaking additives. As expected, the high knowledge segment rated their acceptance of these additives slightly, but significantly lower (ie, between 5.3 and 5.6). Artificial color and flavoring were unanimously the least accepted additives, with mean responses ranging from 2.6 to 3.6 and from 2.5 to 3.4, respectively. Significantly, lower acceptance scores were observed for the high knowledge segment, which again might reflect this segment's greater knowledge of wine, ie, their awareness that artificial color and flavor are not permitted wine additives. These findings were perhaps not surprising, given previous studies have found consumers generally consider natural additives to be more appealing and less of a health or environmental concern compared with artificial additives.[38,39] The acceptance of conventional additives, ie, preservatives, acid, oak chips, and tannins, also tended to reflect each segments' level of wine knowledge; with knowledgeable consumers significantly more accepting of winemaking additives (5.3–5.9/9), than low and medium wine knowledge segments (4.3–5.1/9). No significant differences in acceptance were observed between segments for grape sugar extracts, which were somewhat acceptable (5.7–5.9), or gelatin, which was somewhat unacceptable (4.2–4.4), despite both being permitted and commonly used winemaking additives.

With respect to food additives (Table 5), consumers were generally accepting of natural flavoring (6.3–6.7/9), omega 3 fatty acids (7.0–7.3/9), natural color (6.4–6.8/9), minerals (6.4–6.9/9), folate (6.2–6.5/9), and vitamins (7.0–7.5/9), ie, additives likely to be perceived to be natural and/or to afford health benefits. Significant differences were observed between wine knowledge segment responses, but again these were very slight differences (0.3–0.5) and thus not considered to be meaningful. Artificial flavor, artificial color, and monosodium glutamate were the least accepted additives, with acceptance scores ranging from 2.6 to 3.6. Artificial sweeteners were also considered to be unacceptable, with scores ranging from 3.4 to 4.1. Whereas neutral responses (ie, 4.7–4.9/9) were given to salt and thickeners, with no significant differences observed between wine knowledge segment responses.

Collectively, these results demonstrate that consumers are considerably more accepting of natural additives and additives associated with health benefits than the use of artificial additives. Importantly, the results also show that wine consumers accept the use of natural flavor additives and reject the use of artificial flavor additives, and that consumers' wine knowledge impacts their perceptions of additives. Irrespective of their wine knowledge, consumers considered natural flavorings and colors, and additives associated with health benefits (eg, vitamins, minerals, and omega 3 fatty acids) to be acceptable food additives. In contrast, winemaking additives, even commonly used and legally permitted additives such as tartaric acid, preservatives, oak chips, and tannins, were considered far less acceptable, particularly by less knowledgeable consumers.

Consumers were also asked which of the additives listed in Table 4 should be reported on the back label of wine bottles. Consumer responses indicated that those additives with relatively low acceptance scores should be listed on wine labels, ie, preservatives, artificial flavorings, and artificial colors (data not shown). These findings were in agreement with an earlier study concerning consumer perspectives on food labeling, which found consumer support for preservatives and artificial additives to be listed as ingredients.[40]

Consumer flavor preferences in white and red wines

The survey concluded with an optional question asking consumers, "If you could create a wine with your favorite flavors, what would you make?" The ten most popular flavors for inclusion in white and red wines are listed in Table 6. The flavors desired by consumers in white wines (Table 6) were primarily fruit flavors, in particular lemon, citrus, apple, and mango, but vanilla and honey were also among the top ten flavors suggested. These findings correspond with previous research which reported white wine consumers prefer citrus, apricot, apple, and peach.[41] Interestingly, less knowledgeable consumers, who were predominantly women (63.4%), indicated a higher preference for "sweet fruit" flavors in white wines, compared with high knowledgeable consumers. This highlights low knowledge consumers' misuse of the term "sweet", ie, sweetness is a technical description of taste, rather than a description of flavor, but also likely reflects this segments' preference for sweet wine styles. This finding is in agreement with a previous study concerning the influence of sex on wine selection behavior, which found female wine consumers preferred sweeter wine styles and fruity, vanilla flavors, whereas men instead preferred oak, spice and pepper aromas.[42]

The flavors desired by consumers in red wines were again predominantly fruit flavors, particularly berry fruits such as raspberry, blackberry, blackcurrant, and strawberry. Again, this was in agreement with previous findings that red wine consumers have strong preferences for "berry" aromas, including cherry, plum, blackberry, redcurrant, raspberry, and strawberry.[42] Furthermore, attributes associated with oak maturation, ie, vanilla, chocolate, and spice, were also suggested. Responses from the low knowledge segment indicated a strong preference for vanilla, which provides valuable guidance to industry with respect to developing wine styles targeted specifically to less knowledgeable consumers.

Table 6 Consumer preferences for flavors in white and red wines

Wine flavor	Wine knowledge segments		
	Low (n=271, 26.3%)	Medium (n=528, 51.2%)	High (n=232, 22.5%)
White wine			
Lemon	14.9	13.8	20.0
Citrus	10.3	17.9	17.5
Fruity	13.8	12.2	10.0
Apple	9.2	13.0	15.0
Mango	9.2	13.0	7.5
Lime	9.2	7.3	7.5
Passion fruit	10.3	4.9	10.0
Sweet fruit	11.5	4.9	0
Vanilla	4.6	8.1	5.0
Honey	6.9	4.9	7.5
Red wine			
Vanilla	29.9	12.6	7.2
Blackcurrants	8.1	10.3	15.8
Chocolate	9.0	13.2	15.9
Raspberry	10.4	12.6	5.8
Mixed spice	9.0	10.1	10.1
Berry	4.5	9.4	11.6
Strawberry	14.9	7.5	5.8
Blackberry	11.9	13.8	21.7
Cherry	4.5	5.7	8.7
Fruity	4.5	6.9	5.8

Note: Data are presented as percentages for top ten flavors within wine knowledge segments.

Conclusion

Current legislation does not permit the addition of flavorings to wine, despite their routine use by other food and beverage industries to enhance aroma, flavor, and consistency. The wine industry could potentially utilize flavor additives to improve wine quality, for example in seasons where ideal fruit composition cannot be achieved without intervention and/or to tailor wine sensory attributes to meet the specific expectations and preferences of different segments of the target market. Findings from this study suggest most consumers would be more accepting of the addition of natural flavorings to wine, than of many of the additives currently used in winemaking, albeit consumers' wine knowledge influenced their perceptions of and attitudes toward winemaking additives. Future research will investigate consumer preferences for wines made with the addition of natural flavorings. There are conflicting views regarding whether or not food additives should be used during the winemaking process.[43] This study does not advocate one way or the other, but instead sought to assist the wine industry to evaluate the potential benefits that food additives might afford, so that winemakers can make more informed decisions, should legislation change. Finally, a limitation to the study should be acknowledged, ie, that the wine consumers who chose to participate in the survey may have been more interested in and involved with wine than the average Australian wine consumer and that therefore, they possessed a higher level of wine knowledge.

Acknowledgments

The authors gratefully acknowledge Marie Adam for technical assistance; PureProfile for data collection; the wine consumers who participated in the survey; and Renata Ristic for helpful discussions and encouragement. Yaelle Saltman thanks the Australian Grape and Wine Authority for provision of a research scholarship.

Disclosure

The authors report no conflicts of interest in this work.

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Chapter 3. Paper 2 – Natural flavour additives influence the sensory perception and consumer liking of Chardonnay and Shiraz wines.

The use of flavour additives is common practice in food and beverage manufacturing industries, to improve the sensory properties of consumable goods and to better meet consumer expectations. Numerous studies have explored consumer acceptance and/or rejection of food additives, in particular, natural and artificial flavourings.

Current legislation for wine production in Australia prohibits the use of flavour additives, with the exception of beverages classified as 'wine products'. Based on the findings reported in Chapter 2, it is understood that Australian wine consumers are significantly more accepting of natural flavour additives than many legally permissible wine additives (i.e. oak chips, tannins and acid). The survey also identified consumers' preferred flavours in white and red wines, which could be used to inform winemakers during product development.

Based on survey findings, this study has put theory into practice and employed an innovative technique of enhancing aromas and flavours in wines by adding trace amounts of natural flavourings to base wines. Four lower priced commercial wines (two Chardonnay and two Shiraz wines) from a vintage that suffered challenging environmental conditions, were chosen as the base for flavour addition. A range of natural flavour additives including fruit and oak (i.e. vanilla and chocolate) flavourings, were chosen from the list of preferred flavours (described in Chapter 2), and added to the base wines. The aim was to intensify targeted aromas and flavours, whilst mitigating undesirable attributes.

This paper describes the influence of flavour additives on the sensory properties and consumer acceptability of wines. To date, the addition of flavourings to wines has not been explored, therefore this paper serves as a guideline for future research into flavoured wines.

Statement of Authorship

Yaelle. Saltman, Trent E. Johnson, Kerry L. Wilkinson, Renata. Ristic, Leslie M. Norris, Susan E.P. Bastian.

Natural flavor additives influence the sensory perception and consumer liking of Australian Chardonnay and Shiraz Wines. American Journal of Enology and Viticulture, accepted for publication on 10/11/2016.

Yaelle. Saltman, Trent E. Johnson, Kerry L. Wilkinson, Renata. Ristic, Leslie M. Norris, Susan E.P. Bastian (2016).

Natural flavor additives influence the sensory perception and consumer liking of Australian Chardonnay and Shiraz Wines.

Yaelle Saltman

Designed experiments, conducted consumer research (focus groups), sensory descriptive analysis panels and consumer tastings, analysed and interpreted sensory and consumer data, drafted and revised the manuscript. Overall contribution 70%

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis.

Signed Date......8/11/2016.

Trent Johnson

Assisted with experimental design and the interpretation of sensory data, assisted with revising the manuscript.

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Assisted with experimental design and the interpretation of sensory data, assisted with the collection of consumer data (focus groups), assisted with revising the manuscript.

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Signed Date.....7.11.16.....

Natural Flavor Additives Influence the Sensory Perception and Consumer Liking of Australian Chardonnay and Shiraz Wines

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Acknowledgments/Author disclosures

This research was supported by Wine Australia via a PhD research scholarship. The authors gratefully acknowledge: FlavorSense and The Product Makers for provision of flavor additives; Camille Simon and Juliette Descotes for technical assistance with wine analysis; the University of Adelaide staff and students who participated in descriptive analysis of wines; and the consumers who participated in wine sensory evaluations. Finally, we thank industry partners for their generous donation of wines.

Short version of title

Influence of Flavor Additives on Wine

Abstract:

Australian wine consumers have previously indicated their acceptance of the use of flavorings in wine, for the purpose of improving quality. Indeed, consumers were significantly more accepting of natural flavorings than many of the additives currently used in winemaking (e.g. acid, tannins and oak chips). In this study, we therefore chose to investigate the potential for natural flavorings to enhance wine aroma and flavor, and to explore consumer liking of flavored wines. Four lower price point commercial wines (two Chardonnay and two Shiraz wines) were flavored with natural additives to enhance their existing aroma and flavor profile. Descriptive analysis (DA) was performed to determine the sensory profiles of control and flavored wines. Overall, the addition of flavor additives significantly increased the intensity of key attributes (e.g. citrus aroma and honey flavor) and decreased undesirable attributes (e.g. green and earthy notes) in wines. Following DA, consumer tastings (n=218) were conducted to assess liking of control versus flavored wines. Based on individual liking scores, three hedonic clusters were identified. For Chardonnay wines, Cluster 1 (C1) liking was driven by passion fruit aroma, C2 by stone fruit and honey aromas and oak flavor, and C3 by butter aroma, honey flavor, and overall fruit and phenolic length. The drivers for Shiraz wines included: red fruit and confectionary aroma, and chocolate flavor for C1; red berry and green aromas, and oak flavor for C2; and red fruit, confectionary aromas, and oak aroma and flavor for C3. Research findings suggest natural flavorings can be added to wine to enhance sensory properties and, for some segments of the consumer market, wine acceptability (or liking).

Key words: consumer acceptance, consumer preference, descriptive analysis, flavor additives, wine, segmentation

Introduction

In today's competitive global market, wine producers are seeking innovative ways to improve wine quality and gain a competitive edge. The wine industry is supported by substantial research efforts, which aim to develop original methods for improving quality, primarily by enhancing desirable aromas and flavors, and by better meeting consumer needs (Saenz-Navajas et al. 2012). To address consumer expectations, the wine industry should incorporate research findings and feedback from wine consumers concerning flavor and wine style preferences; but instead, industry typically assigns stylistic decision making to winemakers (Lattey et al. 2010). According to van Kleef and van Trijp (2005) and Smith (2011), the wine industry invests more resources in marketing to encourage consumers to purchase existing wines, than in determining the wine styles that consumers most prefer (Lesschaeve et al. 2002). This is a classic example of the production versus marketing concept (Sharp 1991).

Other food and beverage industries routinely seek feedback from consumers using qualitative studies and acceptance testing; i.e. consumer responses to products are valued more highly, recognizing consumers as the ultimate user of the final product (Resurreccion 2007). Typically this involves targeted groups of consumers being asked to provide insight into their preferred flavors, tastes, concepts and ideas, which then informs product development and/or marketing strategies (Moskowitz et al. 2012). This practice is considered to be particularly important prior to a novel product first being introduced to the marketplace (Kwak et al. 2013). The flavor profile of foods and beverages can be modified to better meet consumer preferences, e.g. through the use of flavor additives during production. Flavor additives are routinely used by food and beverage producers to enhance aroma and flavor intensity, or to mitigate bitterness and astringency (Branen et al. 2001, Resurreccion 2007).

In most wine-producing countries, strict regulations are in place to govern the additives and/or processing aids that are legally permitted in the production of wine, for example the Australian and New Zealand Food Standard Code (Food Standards Australia New Zealand). Oak chips, tartaric acid and tannins are examples of legal winemaking additives, but the use of flavor additives breaches the legal definition of wine, being 'the product of the complete or partial fermentation of fresh grapes, or a mixture of that product and products derived solely from grapes'. Currently, the addition of flavoring(s) to wine renders it a 'wine product', i.e. 'a food containing no less than 700 mL/L of wine which has been formulated, processed, modified or mixed with other foods. Examples of traditional wine products include Vermouth and Retsina, which are wines flavored with botanicals (e.g. flowers, herbs or spices) and pine resin, respectively.

In some vintages, the quality of fruit (and therefore wine) is downgraded due to diminished aroma and flavor intensity arising from challenging environmental conditions, e.g. drought or late seasonal rain (Soar, Sadras, and Petrie 2008). Flavorings might afford industry a means by which such quality losses could be mitigated; i.e. the addition of flavorings to low quality wines could improve their palatability, in the same way that existing winemaking additives are already used for corrective purposes (Lesschaeve and Noble 2005). A recent study investigating wine consumers' acceptance of and attitudes towards the use of additives during winemaking found consumers were more accepting of the addition of natural flavorings to wine than many of the (legally) approved wine additives, e.g. oak chips, tartaric acid and tannins (Saltman et al. 2015). This suggests that if flavorings became permissible winemaking additives, many Australian wine consumers would accept the final product.

To date, the potential for flavorings to be used as legitimate winemaking additives for improving wine quality (rather than for the production of novel flavored wines) has not been reported in the literature. This study therefore aimed to address several important research questions: Can flavor additives influence the sensory properties of commercial wine? Can flavor additives mitigate perceptions of astringency and bitterness? Can flavor additives influence consumer liking of wine? This research demonstrates the potential for flavor additives to be used in winemaking and provides a methodological framework for enhancing wine aroma, flavor and palatability, based on consumer preferences.

Materials and Methods

Preparation of flavored wines. Two prominent grape varieties were chosen as the base wines for flavoring in this study: Chardonnay (CH1 and CH2) and Shiraz (SH1 and SH2). Four lower price point wines (i.e.≤ AUD$10) were sourced commercially, i.e. two wines for each variety. The wines were from the 2011 vintage, which was considered a relatively poor year in some Australian wine regions due to unusually heavy rainfall, disease pressure and cool conditions. The retail price of wines was AUD$7 to AUD$10 per bottle.

Natural flavor additives (Table 1) sourced from the Product Makers Pty Ltd (Melbourne, Australia) and FlavorSense Corporation (San Rafael, CA, USA) were diluted (1/100) in a 20% aqueous ethanol solution (food grade, Tarac Technologies Pty. Ltd., Nuriootpa, Australia) and the resulting stock solution stored at 4°C. Flavors were chosen based on the findings of an earlier study (Saltman et al. 2015), with bench-top trials involving the addition of various combinations of flavorings to base wines carried out to optimize flavor intensity and overall sensory properties. Focus panels were assembled to evaluate the prototype flavored wines and flavor combinations were refined based on the feedback obtained. This enabled development of two flavored versions of each base wine (Table 1).

Once the final composition of flavorings was determined, base wines were spiked, and control and flavored wines were bottled under screw-cap. Briefly, this involved transferring wines from their original commercial bottles into 20 L stainless steel vessels, after which flavor additives were spiked at the required concentrations (Table 1); dry ice and potassium metabisulphite (20 ppm) were added to prevent oxidation. Wines were stored overnight at ambient temperature, prior to bottling. Wines were manually syphoned into 375 mL glass bottles with metal screw-cap closures, with minimal ullage and carbon dioxide blanketing. Bottles were stored at 15°C until required for chemical and sensory analysis.

Chemical analysis. The pH, titratable acidity (TA, as g/L of tartaric acid) alcohol (% v/v), residual sugar (as g/L of glucose and fructose) and volatile acidity (VA, as g/L of acetic acid) of control and flavored wines were measured (in duplicate) according to published methods (Iland et al. (2004).

Descriptive analysis (DA). DA was performed to generate comprehensive sensory profiles of control and flavored wines. Eleven trained panelists (6 females, 5 males, aged between 22 and 60 years) participated in the DA of Chardonnay wines; twelve trained panelists (7 females, 5 males, aged between 22 and 60 years) participated in the DA of Shiraz wines. Panelists underwent five training sessions (1 x 2 hr session per week, held over 5 consecutive weeks). During training sessions, the panel evaluated the aroma, flavor, taste and mouthfeel attributes of each wine, according to DA protocol (Lawless and Heymann 1999) and were introduced to the tasting booths in which formal evaluations would be held, (using controlled ventilation, temperature (22–23°C) and light conditions). The white wine DA panelists generated nine aroma, six flavor, and six taste and mouthfeel descriptors, while the red wine DA panelists identified eight aroma, six flavor, and five taste and mouthfeel descriptors. Reference standards (Table 2), developed during early training sessions, were freshly prepared in covered opaque black glasses and provided at each subsequent training session and throughout formal evaluations.

During training, panelists practiced rating the intensity of each descriptor, with a subset of wines being assessed in replicate. This data was analyzed to monitor judge by sample interactions and when any significant interactions were minimized, panel performance was considered satisfactory and formal evaluations commenced. Two formal evaluation sessions were held, with 24 wines presented over two sessions, such that four replicates of each wine were assessed. Wines (30 mL) were assigned random three digit codes and served in XL5 (ISO standard) clear wine glasses covered with plastic lids, using a randomized presentation order, with wines presented in brackets of six. Chardonnay wines were served at 14–16°C and Shiraz wines were served at 22–24°C. Panelists evaluated wines and recorded the intensity of each sensory attribute using FIZZ data acquisition software (Version 2.47b, Biosystèms, Couternon, France) and 15 cm unstructured line scales with anchor points of ‘low’ and ‘high’ intensity placed at 0% and 100% of the scale. Between each sample, panelists cleansed their palate with filtered water and unsalted crackers during a one minute break. Panelists were required to have five minute breaks after each bracket. All samples were expectorated.

Consumer acceptance testing. Consumer acceptance testing occurred four weeks after DA. 218 consumers were recruited (107 for Chardonnay tastings and 111 for Shiraz tastings), via methods including flyers posted in public places and from an internal wine consumer database.

Inclusion criteria required participants to be of legal drinking age (i.e., ≥ 18 years of age) and to have regularly consumed Chardonnay or Shiraz wine (i.e., consumption frequency ≥ once per month). Consumers attended a single tasting session (either the white wine tasting or the red wine tasting), depending on their wine preferences and consumption. Tastings were conducted in the same sensory laboratory used for DA. During each session, consumers tasted six wines (30 mL each) presented in random order, in XL5 (ISO standard) wine glasses labelled with a 3-digit code and covered with plastic lids. Chardonnay wines were served at 14–16°C and Shiraz wines were served at 22–24°C. Prior to tasting, participants were instructed on how to taste the wine and how to use the hedonic scale. Panelists received three wines at a time, and used a signal button to indicate when they were ready to receive their next three samples. Consumers were asked to indicate their liking of each wine using a nine-point category scale, where 1 = extremely dislike, 5 = neither like nor dislike, and 9 = extremely like. Consumers were also asked to complete a questionnaire which captured their demographics. Data were collected using paper scoresheets, which were subsequently analyzed by XLSTAT (version 2011.5.01, Addinsoft).

Data analysis. Data were analyzed using a combination of methods: XLSTAT (version 2011.5.01, Addinsoft) for one-way analysis of variance (ANOVA), where mean comparisons were performed by Fisher's least significant difference (LSD) post hoc test at $P<0.05$, Discriminant Analysis and partial least square regressions (PLSR); SPSS 20 (IBM Corporation, Armonk, NY, USA) for cluster analysis to identify hedonic clusters. A mixed model two-way ANOVA was used to analyze sensory data from DA, with assessors and samples (wines) treated as random and fixed factor effects, respectively. Principal component analysis (PCA) was performed using SENPAQ (version 5.01, Qi Statistics, Reading, UK) and XLSTAT (version 2011.5.01, Addinsoft).

Results

Chemical composition of wines. Basic wine chemistry measurements (i.e., pH, TA, alcohol, residual sugar and VA) for control and flavored Chardonnay and Shiraz wines are reported in Table 3. Results show the addition of flavorings had no significant impact on these parameters.

Sensory profiles of wines. Figures 1a and 1b illustrate the sensory profiles of control and flavored Chardonnay and Shiraz wines, respectively; the radial axis represents the intensity of key aroma (designated by A), flavor (designated by F), taste and mouthfeel attributes.

Chardonnay wines. The DA panel rated 21 white wine attributes, 16 of which were found to significantly differentiate control and flavored Chardonnay wines (Figure 1A). The spider plot for CH1 and its corresponding flavored wines, CH1+A and CH1+PF, clearly demonstrate the addition of flavorings influenced wine sensory profiles. The intensity of orange blossom and citrus aroma, and oak flavor of CH1+A were almost double that of CH1, while stone fruit aroma, and caramel candy and mixed spice flavors were also rated much higher. Taste and mouthfeel attributes were also affected; phenolic aftertaste (the persistence of phenolic taste in the mouth after expectorating), fruit aftertaste (the persistence of fruit taste in the mouth after expectorating), creaminess and astringency were all significantly lower than for CH1. In the case of CH1+PF, the panel perceived citrus and stone fruit aromas to be considerably more intense compared with the base wine (CH1).

The spider plot for CH2 and its corresponding flavored wines, CH2+H and CH2+PF, demonstrate the addition of honey, butter and vanilla flavorings to CH2 resulted in significantly enhanced stone fruit aroma and oak flavor for CH2+H, but surprisingly, a significant increase in honey flavor was not observed. In the case of CH2+PF, the perceived intensity of most taste and mouthfeel attributes, including bitterness, acidity, astringency and phenolic aftertaste, and to a lesser extent creaminess, was higher than for CH2. However, the intensity of passion fruit aroma was lower compared with CH2.

Shiraz wines. The DA panel rated 19 red wine attributes, 10 of which were found to discriminate control and flavored wines (Figure 1b). The spider plot for SH1 and its corresponding flavored wines, SH1+C and SH1+R, demonstrate the impact of flavor additives on red wine sensory profiles. The addition of flavorings to SH1 not only increased the intensity of confectionary and chocolate-vanilla aromas and flavors, but also diminished the intensity of green ('stemmy') and earthy ('dusty and moldy') aromas, and bitterness, in SH1-R. Changes in the sensory profile of SH1+C were subtle; only slight decreases in green, earth and red berry aromas were observed, compared to SH1.

In the case of SH2, the addition of flavorings enhanced confectionary, chocolate-vanilla and red berry characters, and diminished oak flavor in SH2+B, but SH2+R and SH2 had similar profiles.

Consumer liking of wines. The mean consumer hedonic data did not reveal any statistical difference in the liking of control and flavored wines, indicating that at the aggregate level, there was very little product differentiation (Stone and Siedel 2004). Cluster analysis based on individual liking scores to identify consumer segments with differing preferences for each of the wines was undertaken next. ANOVA not only confirmed significant differences between the liking scores of different clusters, but also demonstrated significant differences between the liking scores given to individual wines within clusters (Table 4), which identified several instances in which flavored wines were liked more than their corresponding base wine.

Chardonnay wines. A three-cluster solution was found for Chardonnay wines (Table 4), with discriminant analysis revealing a 91.6% fit for the data set. The hedonic clusters for control and flavored Chardonnay wines comprised: cluster 1 (C1, n=51) who tended to like all wines;

cluster 2 (C2, n=25) who did not particularly like any of the wines; and cluster 3 (C3, n=31) who liked control wines, but not flavored wines. Table 5 provides the demographic data for each consumer cluster. Overall, the white wine consumers comprised a higher proportion of female participants (54.2%) than male participants (45.8%), and younger consumers (46.7% of participants were aged between 18 and 29). The younger demographic likely explains why 41.7% of consumers reported incomes < AUD$50,000, despite the majority (81.3%) holding undergraduate qualifications. When hedonic clusters were compared, C1 was found to comprise young male consumers (43.1% aged between 18 and 29, and 54.9% male), with lower incomes (48% earned < AUD$50,000) and undergraduate qualifications (74.5%). In contrast, C2 and C3 comprised younger female consumers (60–64.5% female participants, 48.0–51.6% aged between 18 and 29); the majority (≥83.9%) of whom held undergraduate qualifications.

Shiraz wines. A three-cluster solution was also obtained for Shiraz wines, with discriminant analysis revealing a 96.4% fit for the data set. The hedonic clusters (Table 4) comprised: C1 (n=53), who tended to like all wines; C2 (n=32), who did not particularly like any Shiraz wines; and C3 (n=26), who liked wines with prominent berry and raspberry flavors. Demographic data (Table 5) indicated red wine consumer clusters also comprised a higher proportion of female participants (54.1%), but ages were distributed more evenly than for white wine consumers, albeit there was still a high representation of consumers with undergraduate qualifications (being 74.3%). Household income varied, with 42.6% and 32.4% of consumers reporting annual earnings of AUD$50,000–$100,000 and AUD $100,00–$200,000 per annum, respectively. C1 comprised 52.8% male participants and 47.8% female participants, most of whom were aged ≥ 40 years. The majority of C2 and C3 consumers were female (62.5 and 57.7%, respectively), with more than half holding postgraduate qualifications.

Principal component analysis (PCA). PCA of sensory data and liking scores for control and flavored Chardonnay and Shiraz wines resulted in the bi-plots shown in Figures 2a and 2b.

Chardonnay wines. 80.6% of variation observed amongst Chardonnay wines was explained by the first two PCs (Figure 2a). CH1 is situated in the upper right quadrant, and its positioning is largely driven by taste and mouthfeel attributes, i.e., phenolic and fruit aftertaste, creaminess. The corresponding flavored wines, CH1+A and CH1+PF, were located in the lower left quadrant; with orange blossom, citrus and stone fruit aromas, and mixed spice and caramel candy flavors as key vectors. CH2 was located at the top of the bi-plot, with CH2+H in close proximity. Passion fruit aroma and fruit aftertaste were the main drivers influencing the positioning of these wines, whereas CH2+PF, which was located in the lower right quadrant, was instead influenced by taste and mouthfeel attributes, i.e. acidity, bitterness, astringency, creaminess and phenolic aftertaste. Consumer segment C1 was located below the origin of the bi-plot, which reflects C1 consumers' moderate liking of all wines (hedonic scores ranged from 5.78 to 6.54). In contrast, C2 (the segment that didn't particularly like any wines) was positioned in the lower left quadrant, near to CH1+A, which this segment gave their highest rating (being 5.04), but furthest away from CH1 (which they rated 3.2). C3, the cluster that most liked the control wines (CH1 and CH2), followed by CH2+H, was situated in proximity to these three wines.

Shiraz wines. 90.4% of variation amongst Shiraz wines was explained by the first two PCs (Figure 2b). SH1 and SH1+C had similar sensory profiles (Figure 1b) and not surprisingly were closely positioned on the bi-plot (Figure 2b). SH1+R was situated on the opposite side of the bi-plot, due to the influence of chocolate-vanilla aromas and flavors, and confectionary flavor. SH2 and its corresponding flavored wines (SH2+R and SH2+B) were all located in the lower right quadrant. However, SH2+B was located further along the F1 axis, with red fruit aromas and flavors, and confectionary flavor influencing its position.

C1, who tended to like all wines, was situated in close proximity to the wines they liked most, being SH1 (6.43) and SH1+C (6.91), whereas C2, who did not particularly like any wines (liking scores ranged from 3.2 to 5.0), was situated near SH2, their highest rated wine. Finally, C3 was located amongst SH1+R, SH2+R and SH2+B, the wines with enhanced raspberry and berry attributes, which this cluster liked most (liking scores were 6.0 to 6.3).

Partial least squares regression (PLSR). PLSR was performed to explore to what extent the different sensory attributes influenced consumer liking of wines (Figures 3a and 3b). Sensory attributes are displayed along the x-axis, while regression coefficients for consumer liking are on the y-axis.

Chardonnay wines. The regression coefficients obtained for white wine descriptors suggest C1 consumers generally liked all wines and were not strongly influenced (positively or negatively) by any specific attributes. In contrast, green aroma was a strong negative driver, and honey aroma and oak flavor were moderate positive drivers, for C2 consumer liking. Liking scores of C3 consumers were positively correlated with butter aroma and to a lesser extent honey flavor, but showed a weak negative correlation for oak flavor.

Shiraz wines. The regression coefficients obtained for Shiraz wines suggested C1 consumer moderately disliked red berry and confectionary aromas, and chocolate-vanilla flavor. Hedonic ratings for C1 (Table 4) indicated an overall liking of Shiraz wines (i.e. liking scores ranged from 5.63 to 6.91); but certainly the wines given the lower ratings, i.e. SH1+R and SH2+B, had the most intense red berry aromas and flavors (Figure 1b). Green aromas and oak characters positively affected C2 consumers' liking scores, albeit liking was negatively correlated with chocolate-vanilla aroma. C3 consumers tended to like the attributes that other consumers disliked; their liking was positively influenced by red berry aroma and moderately by confectionary and chocolate-vanilla aromas.

Discussion

Most food and beverage industries routinely use additives to intensify the aroma and flavor of their products (Longo and Sanromán 2006, Routray and Mishra 2011), to mitigate undesirable attributes (e.g., bitterness and astringency), and/or to better meet the specific expectations of their consumers (Resurreccion 2007). These industries have long recognized the fiscal benefits associated with meeting consumer need/demand (Costa and Jongen 2006, McEwan 1996). In this study, we explored consumer acceptance of flavored wines and the potential for flavor additives to enhance the sensory attributes of commodity wines. Flavor additives were chosen based on previous research which evaluated consumer preferences for white and red wine attributes (Lattey et al. 2010, Lattey et al. 2007, Saltman et al. 2015).

Importantly, the choice of flavorings was also intended to enhance a range of aromas and flavors whilst maintaining the existing style of base wines; i.e. in contrast to wine products, which are typically intended to display a dominant aroma or flavor characteristics (e.g., elderflower, blueberry).

The combination of flavor additives used were optimized via bench top and focus group tastings, with modifications made based on consumer feedback. DA profiled the aroma, flavor, taste and mouthfeel attributes of control and flavored wines (Figures 1a and 1b) and confirmed the addition of flavorings enhanced wine aroma and flavor. Base wine style was retained, with two exceptions. Firstly, CH2+PF was considered to exhibit unusually high levels of bitterness, acidity and astringency (Figure 1a), despite chemical analysis confirming no significant change to pH or TA (Table 3). Previous studies have shown certain aromas can enhance perceptions of sweetness, even though they cannot directly impart taste properties (Clark and Lawless 1994, Stevenson et al. 1998), which has been attributed to learned associations (Stevenson et al. 1998) and/or cross-modal interactions (Auvray and Spence 2008). In the current study, the addition of passion fruit flavorings to CH2 base wine increased the perception of bitterness and acidity, while the intensity of phenolic aftertaste was also perceived to be higher following the addition of passion fruit or honey flavoring to CH2 (Figure 1). The impact of flavor addition on wine phenolics is not known, since total phenolics were not measured. However, there is literature precedent for volatile compounds and flavor additives stimulating trigeminal nerve activity (Delwiche 2004, Auvray and Spence 2008). Future research therefore warrants further investigation into possible cross-modal interactions.

The second exception to base wine style was observed in SH1+R, which exhibited exceptionally high confectionary and chocolate-vanilla aromas and flavors (Figure 1b), albeit this might be attributed to the addition of butter and custard flavors. Nonetheless, the flavor additions clearly influenced the sensory perception of base wines, thereby addressing a key research question for the study.

To the best of our knowledge, this is the first study investigating the use of flavor additives to enhance the aroma, flavor and/or quality of wine. Future research should focus on interactions between flavor additives and the existing aroma and flavor profiles of base wines, in order to further optimize flavor enhancement. As in the current study, this is likely to be facilitated through the involvement of flavor producers and sensory professionals, as suggested by Lesschaeve, Norris and Lee (2002). Importantly, the addition of flavorings reduced the intensity of green and earthy characters, which are often considered to be undesirable wine attributes (Lesschaeve and Findlay 2004, Hopfer and Heymann 2014). Mitigating the impact of undesirable attributes can improve the perceived quality of wine, possibly increasing the likelihood of repurchase (Francis and Williamson 2015).

The aroma and flavor of wine is complicated and small changes in composition can significantly impact on sensory perception due to chemical, physiological and/or cognitive interactions (Keast and Breslin 2003). An interesting phenomenon was observed in this study, whereby addition of similar flavorings to two different base wines gave significantly different sensory outcomes. The addition of passion fruit flavoring to CH1 and CH2 (at 2.3 and 2.2 g/L, respectively), resulted in enhanced stone fruit, citrus and passion fruit aromas in CH1+PF, whereas CH2+PF was perceived to be acidic, bitter and astringent (Figure 1a). More detailed chemical analyses (e.g. profiling the volatile composition of flavorings and flavored wines by gas chromatography-mass spectrometry) might provide insight into any interactions occurring between additives and wine constituents (Guth 1997).

Following DA, consumer tastings were held to determine consumer liking of control and flavored wines. Consumers evaluated wines in blind tastings and rated their liking using 9-point scales. As expected, there was considerable variation amongst individual consumer preferences, so cluster analysis was performed to segment consumers according to their hedonic scores. PCA was subsequently performed on both the liking scores and sensory profiles of Chardonnay and Shiraz wines. The resulting PCA bi-plots illustrate the relationships between wine sensory attributes and consumer liking. This non-linear relationship provides valuable insight into consumers' wine preferences, and when demographic data is taken into consideration, can be used by industry to better market specific wines to different segments of the consumer market. PLSR (Figures 3a and 3b) subsequently defined the contribution of individual sensory attributes (aromas and flavors) on consumer preferences for control and flavored wines. For example, PLSR of Shiraz wines (Figure 3b) suggests confectionary and red berry aromas strongly influenced liking for C3 consumers, but negatively influenced liking for consumers from C1. These results demonstrate the potential value of consumer-based wine sensory and wine marketing research; i.e. to use knowledge concerning the wine preferences of different segments of the consumer market to inform production and/or marketing strategies. However, the prediction of liking or disliking of wines based on sensory attribute drivers may be time dependent, as consumer trends shift, depending on the wine styles available in the marketplace (Lesschaeve et al. 2002).

The current study also succeeded in softening the mouthfeel of CH1, through the addition of a small quantity of an oak flavor additive (i.e. 0.6 g/L). The modest addition of oak flavoring was not expected to yield such a significant sensory outcome, but astringency and phenolic aftertaste were diminished in CH1+A, compared to CH1. The addition of flavorings, whether the oak flavor additive alone, or together with the apricot and butter flavorings, also improved C1 and C2 consumers' likings of CH1. An earlier study found a considerable proportion of Australian wine consumers to be accepting of wines made using alternative methods of oak maturation, i.e. instead of traditional barrel maturation (Crump et al. 2014). Flavorings could therefore be used to impart oak characters to wine, without the need for time-intensive oak maturation, in a convenient, cost-effective manner that would likely be deemed acceptable to at least some consumer segments.

Finally, the potential for lower price point wines to be made more palatable to some consumer segments through the addition of corrective flavorings represents an attractive opportunity for the wine industry; particularly given flavor additions could be made at various stages of production. The findings from this study therefore provide the wine industry with a viable option for enhancing the quality of finished wines, subject to regulations governing the use of additives in wine production.

Conclusion

The current study explored the potential for natural flavor additives to be used to enhance the sensory properties of relatively inexpensive commercial wines, thereby improving their consumer appeal. The study demonstrates the way in which consumer feedback can be used to inform decision making, so as to more closely align wine style with consumer preferences. The use of flavorings did not improve consumer liking of all wines; as always, there was considerable variation in consumers' wine preferences. However, segmentation identified clusters of consumers who were accepting of flavored wines and in some cases, flavored wines were preferred to control wines. For now, flavor additives are not legally permitted winemaking aids, so their use is entirely academic; nonetheless, this study serves to demonstrate their potential application, e.g. their capacity to mitigate sensory deficiencies, a lack of flavor intensity, bitterness and/or phenolic aftertaste. Optimization of flavorings is by no means a trivial undertaking, and should therefore be undertaken with advice from flavorists and sensory scientists, as well as consumers, in what would represent a more consumer-oriented approach to winemaking.

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Figure Captions

Figure 1 Spider plots showing mean intensity scores for the aroma (A), flavor (F), taste and mouthfeel attributes of control and flavored (a) Chardonnay and (b) Shiraz wines. Asterisks (*) denote statistical significance at $p < 0.05$.

Figure 2 PCA bi-plots of sensory attributes for control and flavored (a) Chardonnay and (b) Shiraz wines, and the positioning of hedonic clusters (C1, C2, C3).

Figure 3 Partial Least Squares (PLS) regression for control and flavored (a) Chardonnay and (b) Shiraz wines, according to hedonic clusters (C1, C2, C3).

Table 1 Composition of flavorings added to Chardonnay and Shiraz wines.

Wine	Flavor target	Code	Flavor additives
Chardonnay 1	apricot	CH1+A	1.8 g/L apricot[a], 0.6 g/L oak[a], 2.2 g/L butter[a]
	passion fruit	CH1+PF	2.3 g/L passion fruit[a], 2.2 g/L butter[a], 0.5 g/L custard[b]
Chardonnay 2	honey	CH2+H	1.4 g/L honey[a], 1.5 g/L butter[a], 0.2 g/L vanilla[b]
	passion fruit	CH2+PF	2.2 g/L passion fruit[a], 1.5 g/L butter[a]
Shiraz 1	chocolate	SH1+C	3.0 g/L butter[a], 1.0 g/L cinnamon[b], 1.5 g/L orange[b], 2.9 g/L chocolate[b]
	raspberry	SH1+R	3.0 g/L butter[a], 1.6 g/L orange[b], 2.2 g/L custard[b], 0.5 g/L raspberry[a]
Shiraz 2	berry	SH2+B	1.7 g/L berry[a], 0.4 g/L custard[b], 1.8 g/L butter[a]
	raspberry	SH2+R	0.5 g/L raspberry[a], 2.1 g/L butter[a]

Flavor additives spiked into base wines as 1% stock solution (20% aqueous ethanol).
[a]Flavor additives sourced from FlavorSense Corporation (apricotWW3; oak; butter10-1206; passion fruit77116; honey; berry8819).
[b]Flavor additives sourced from The Product Makers (vanilla1729; cinnamon1525; orange1883; chocolate1039; custard1989; raspberry228).

Table 2 Reference standards used in descriptive analysis of Chardonnay and Shiraz wines.

Attribute	Reference standard	Definitions
Chardonnay descriptors		
Passion fruit	4 drops passion fruit flavor additive[a]	fresh passion fruit
Stone fruit	1 cm cube of white peach + nectarine, 4 drops apricot flavor additive[a]	fresh peach, yellow nectarine and apricots
Citrus	1 cm cube mandarin + lemon + orange	fresh lemon, mandarin and orange
Green	0.15 g freshly cut grass	freshly cut grass
Honey	½ tbsp of honey (Capilano)	honey and musk
Butter	5 drops butter flavor additive[b]	aroma of butter
Orange blossom	0.3 g freshly cut leaves from an orange tree	aroma of orange blossom, floral
Mixed spice	¼ tsp of allspice (McKenzies) + 4 drops cinnamon flavor additive[b]	cinnamon, nutmeg and cloves
Oak	0.07 g medium toast American oak chips (O.C. Inc.)	toasted oak
Caramel candy	1 caramel candy (Coles brand) cut in small pieces	vanilla and caramel candy
Shiraz descriptors		
Red berry	2 frozen raspberries + 1 frozen strawberry (McCains)	fresh raspberry and strawberry
Confectionary	6 drops raspberry flavor additive[a] + 6 drops berry flavor additive[a]	chewing gum (hubba bubba) strawberry and cream candy
Chocolate-vanilla	3 drops vanilla flavor additive[b] + 10 drops chocolate flavor additive[b]	chocolate and vanilla
Earthy	30 g wet earth	dusty and moldy
Green	2 frozen blackcurrants + 1 frozen blackberry (McCains)	stemmy and stalky
Oak	0.07 g medium toast American oak chips (O.C. Inc.)	toasted oak
Mouthfeel descriptors		
Creaminess	low fat milk (low) to full cream milk (high)	perception of roundness on the palate
Acidity	tartaric acid (low 0.5 g/L – high 2g/L)	level of acid perceived
Bitterness	quinine sulfate (low 5mg/L – high 20 mg/L)	perception of bitterness
Astringency	felt material (low) – sandpaper (high)	perception of drying or puckering sensation
Fruit/phenolic aftertaste		length of time fruit/phenolic attributes were perceived after expectoration

Standards were prepared in 30 mL of unoaked Chardonnay or Shiraz bag-in-box wine.
Flavor additives spiked into reference standards as 1% stock solution (20% aqueous ethanol).
[a]Flavor additives sourced from FlavorSense Corporation.
[b]Flavor additives sourced from The Product Makers.

Table 3 pH, titratable acidity (TA), alcohol content, residual sugar content and volatile acidity (VA) of Chardonnay and Shiraz wines.

Wine	pH	TA[a] (g/L)	Alcohol (% v/v)	Sugar[a] (g/L)	VA[a] (g/L)
CH1	3.5	6.2	12.9	4.6	0.5
CH1+A	3.5	6.2	12.9	4.6	0.5
CH1+PF	3.5	6.1	12.9	4.6	0.5
CH2	3.4	6.6	12.0	2.6	0.2
CH2+H	3.4	6.6	12.0	2.7	0.2
CH2+PF	3.4	6.6	12.0	2.6	0.2
SH1	3.6	6.2	13.8	0.5	0.5
SH1+C	3.6	6.1	13.9	0.5	0.5
SH1+R	3.6	6.1	13.8	0.5	0.5
SH2	3.6	5.9	13.2	4.6	0.5
SH2+B	3.6	5.9	13.2	4.5	0.5
SH2+R	3.6	5.8	13.2	4.5	0.5

Values are the means of two replicates.
[a]TA measured as g/L of tartaric acid; residual sugar measured as g/L of glucose and fructose; VA measured as g/L of acetic acid.

Table 4 Consumer liking scores for control and flavored Chardonnay and Shiraz wines.

	Hedonic ratings[a]		
	Cluster 1 (n=51, 48%)	**Cluster 2 (n=25, 23%)**	**Cluster 3 (n=31, 29%)**
CH1	$5.78^{a/b}$	$3.24^{b/c}$	$6.26^{a/a}$
CH1+A	$6.41^{a/a}$	$5.04^{b/a}$	$3.16^{c/d}$
CH1+PF	$6.53^{a/a}$	$3.72^{b/bc}$	$3.81^{b/cd}$
CH2	$6.31^{a/ab}$	$3.60^{b/bc}$	$6.00^{a/a}$
CH2+H	$6.09^{a/ab}$	$4.44^{c/ab}$	$5.13^{b/b}$
CH2+PF	$6.54^{a/a}$	$3.40^{c/c}$	$4.60^{b/bc}$
	Cluster 1 (n=53, 48%)	**Cluster 2 (n=32, 29%)**	**Cluster 3 (n=26, 23%)**
SH1	$6.43^{a/a}$	$3.93^{b/b}$	$4.81^{b/b}$
SH1+C	$6.91^{a/a}$	$3.18^{c/c}$	$4.09^{b/b}$
SH1+R	$5.65^{a/b}$	$3.31^{b/bc}$	$6.25^{a/a}$
SH2	$6.43^{a/a}$	$5.00^{b/a}$	$4.09^{b/b}$
SH2+B	$5.63^{a/b}$	$4.15^{b/ab}$	$6.34^{a/a}$
SH2+R	$6.04^{a/ab}$	$3.87^{b/b}$	$5.96^{a/a}$

[a]Hedonic ratings were determined using a 9-point scale (1=extremely dislike, 5=neither like nor dislike, 9=extremely like).

Values followed by different letters (i) within a row are significantly different between clusters/(ii) within a column are significantly different within clusters ($P \leq 0.05$, one-way ANOVA, Fisher's LSD post hoc test).

Table 5 Demographics for white and red wine consumers (as total samples and hedonic clusters).

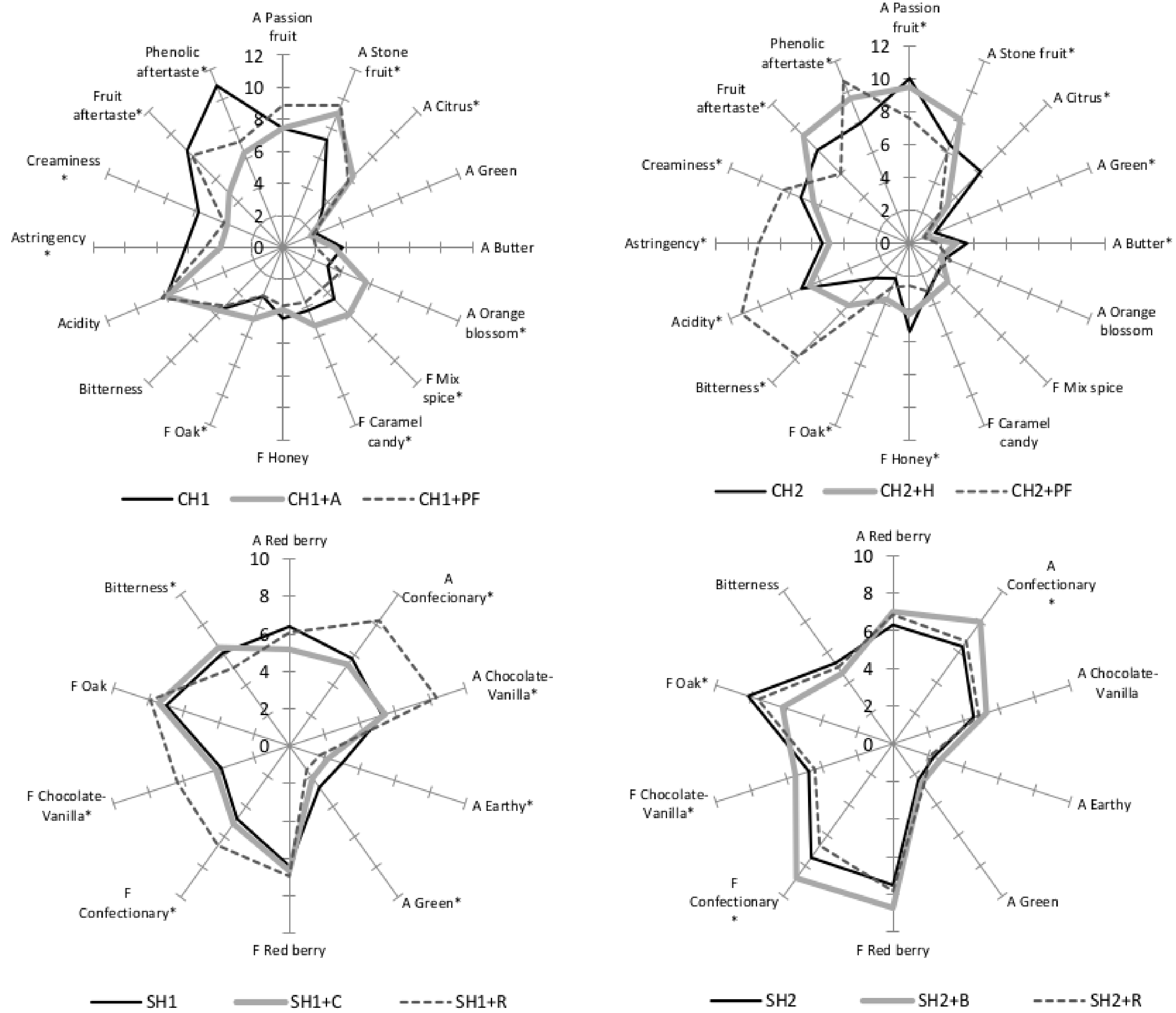
	White wine consumers				**Red wine consumers**			
	total sample (n=107)	**Cluster 1 (n=51, 48%)**	**Cluster 2 (n=25, 23%)**	**Cluster 3 (n=31, 29%)**	**total sample (n=111)**	**Cluster 1 (n=53, 48%)**	**Cluster 2 (n=32, 29%)**	**Cluster 3 (n=26, 23%)**
Gender								
Male	45.8	54.9	40.0	35.5	45.9	52.8	37.5	42.3
Female	54.2	45.1	60.0	64.5	54.1	47.2	62.5	57.7
Age								
18–29	46.7	43.1	48.0	51.6	23.4	24.5	25.0	19.3
30–39	24.3	23.5	28.0	22,6	22.5	13.3	34.4	26.9
40–54	19.6	25.5	20.0	19.6	32.4	35.8	28.1	30.8
55+	9.4	7.8	4.0	16.1	21.7	26.4	12.5	23.0
Education								
Secondary/TAFE	18.7	25.5	8.0	16.1	25.7	34.6	21.9	12.0
Undergraduate	39.3	33.3	44.0	45.2	31.2	32.7	25.0	36.0
Postgraduate	42.0	41.2	48.0	38.7	43.1	32.7	53.1	52.0
Income[a]								
<$50K	41.7	48.0	39.1	33.3	20.4	21.1	22.6	16.0
$50K–$100K	32.0	26.0	30.4	43.3	42.6	44.2	45.2	36.0
$100K–200K	10.7	8.0	17.4	10.0	32.4	28.9	32.2	40.0
>$200K	15.6	18.0	13.0	13.3	4.6	5.8	0.0	8.0

Values are expressed as percentages.
[a]Australian dollars (AUD)

Figure 1

(a)

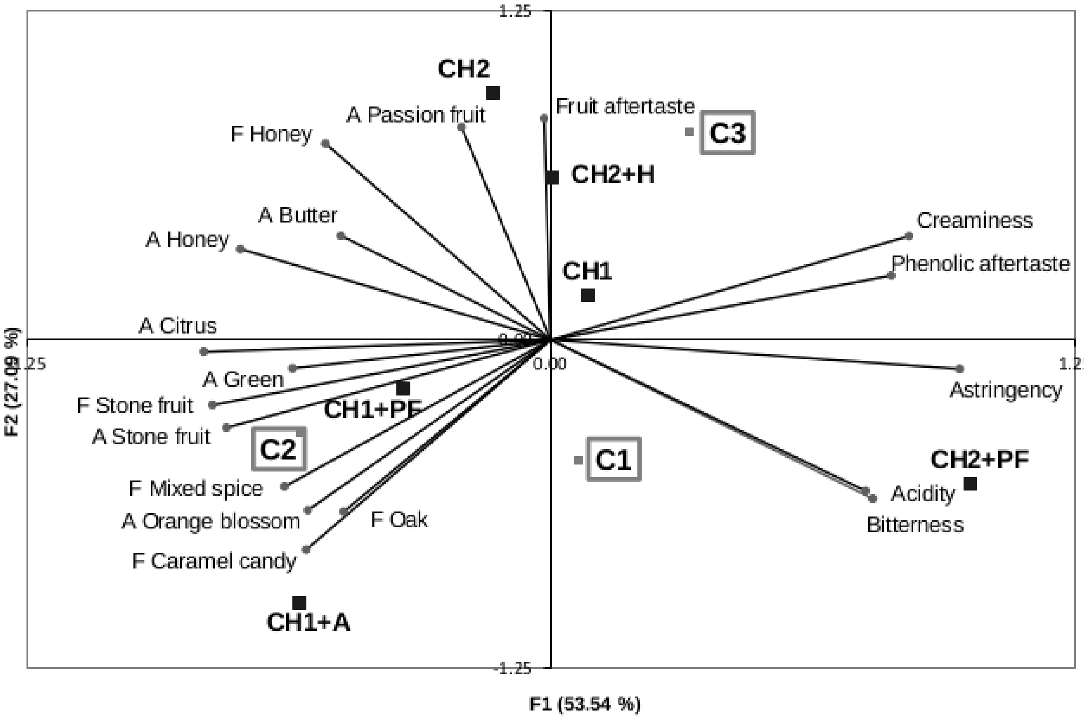
(b)



A Passion fruit
A Stone fruit*
A Citrus*
A Green
A Butter
A Orange blossom*
F Mix spice*
F Caramel candy*
F Honey
F Oak*
Bitterness
Acidity
Astringency *
Creaminess *
Fruit aftertaste*
Phenolic aftertaste*
12
10
8
6
4
2
0
CH1
CH1+A
CH1+PF
A Passion fruit*
A Stone fruit*
A Citrus*
A Green*
A Butter*
A Orange blossom
F Mix spice
F Caramel candy
F Honey*
F Oak*
Bitterness*
Acidity*
Astringency*
Creaminess*
Fruit aftertaste*
Phenolic aftertaste*
CH2
CH2+H
CH2+PF
A Red berry
A Confecionary*
A Chocolate-Vanilla*
A Earthy*
A Green*
F Red berry
F Confectionary*
F Chocolate-Vanilla*
F Oak
Bitterness*
10
8
6
4
2
0
SH1
SH1+C
SH1+R
A Red berry
A Confectionary *
A Chocolate-Vanilla
A Earthy
A Green
F Red berry
F Confectionary *
F Chocolate-Vanilla*
F Oak*
Bitterness
SH2
SH2+B
SH2+R

Figure 2

(a)


1.25
CH2
A Passion fruit
Fruit aftertaste
C3
F Honey
CH2+H
A Butter
A Honey
Creaminess
Phenolic aftertaste
CH1
A Citrus
0.00
-1.25
0.00
1.25
A Green
Astringency
F Stone fruit
CH1+PF
A Stone fruit
C2
C1
CH2+PF
F Mixed spice
Acidity
A Orange blossom
F Oak
Bitterness
F Caramel candy
CH1+A
-1.25
F2 (27.09 %)
F1 (53.54 %)

(b)

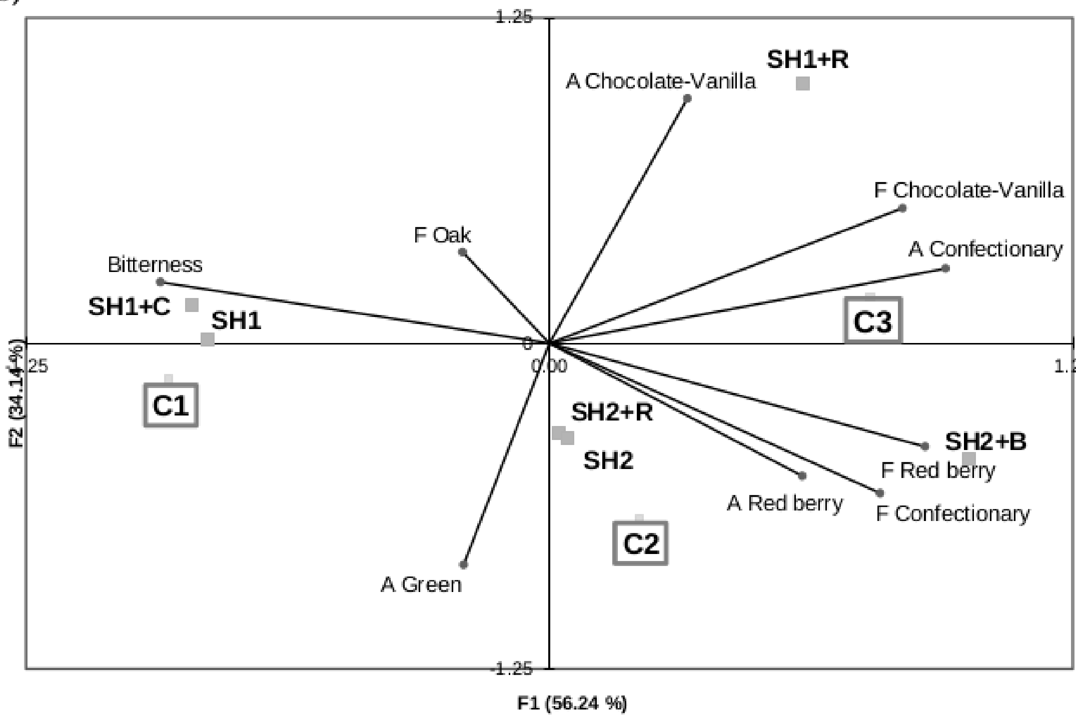
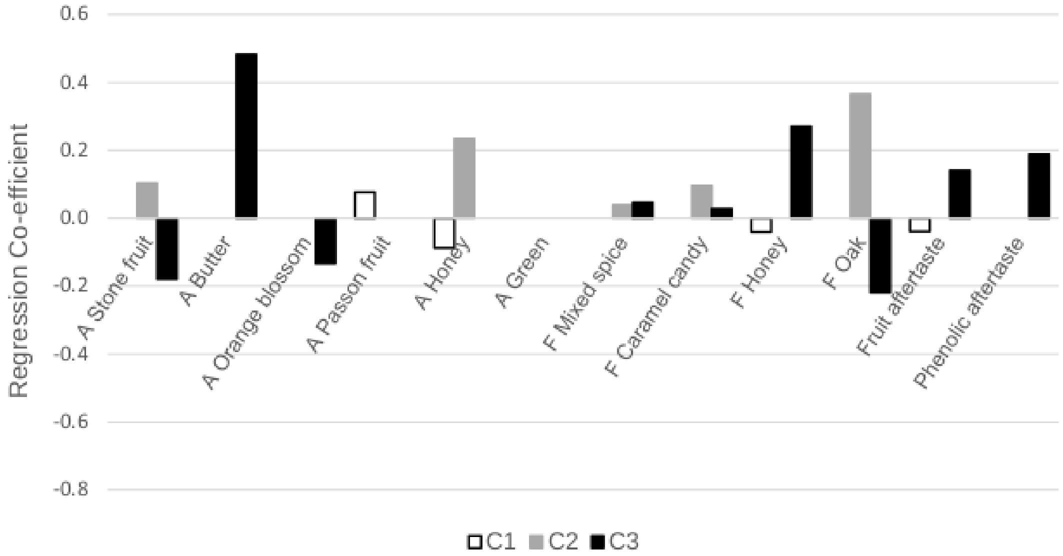
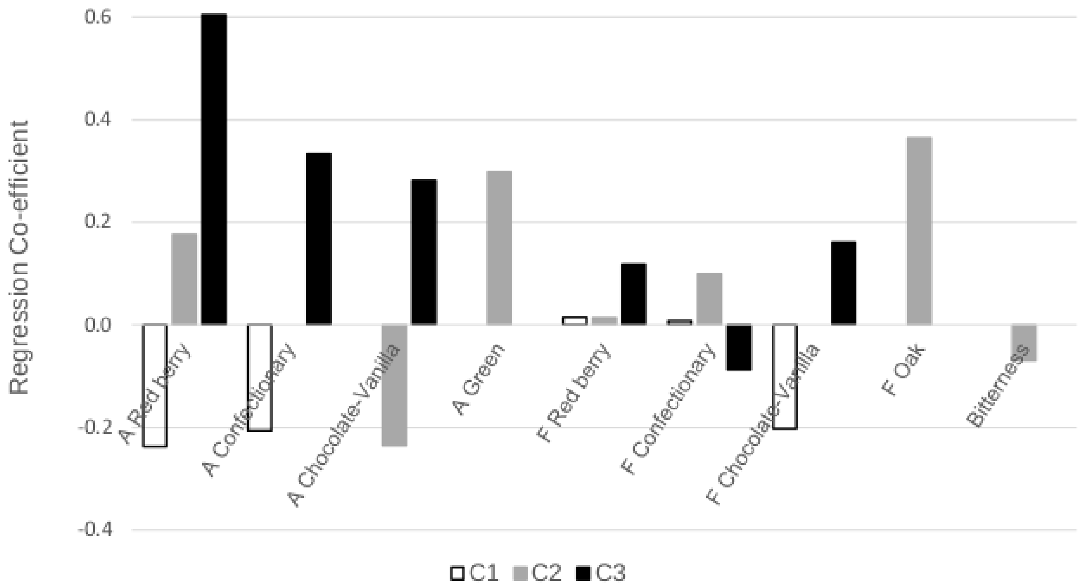

1.25
SH1+R
A Chocolate-Vanilla
F Chocolate-Vanilla
F Oak
A Confectionary
Bitterness
SH1+C
C3
SH1
0
-1.25
0.00
1.25
C1
SH2+R
SH2+B
SH2
F Red berry
A Red berry
F Confectionary
C2
A Green
-1.25
F2 (34.14 %)
F1 (56.24 %)

Figure 3
(a)



0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Regression Co-efficient
A Stone fruit
A Butter
A Orange blossom
A Passon fruit
A Honey
A Green
F Mixed spice
F Caramel candy
F Honey
F Oak
Fruit aftertaste
Phenolic aftertaste
C1
C2
C3

(b)



0.6
0.4
0.2
0.0
-0.2
-0.4
Regression Co-efficient
A Red berry
A Confectionary
A Chocolate-Vanilla
A Green
F Red berry
F Confectionary
F Chocolate-Vanilla
F Oak
Bitterness
C1
C2
C3

Chapter 4. Paper 3 - Impact of bottle ageing on the composition and sensory properties of flavoured Chardonnay and Shiraz wines

Wine is a complex matrix containing a vast array of volatile compounds, derived from grapes, fermentation and ageing. When flavourings (chemical compounds that impart aromas and flavours) are added to the mixture, they interact with the vast array of existing constituents in wine. The study described in Chapter 3 demonstrated that the application of natural flavourings (in trace amounts), resulted in significant changes to a wine's sensory profile and consumer liking. Chemical analysis of the wines confirmed that flavourings did not affect wine pH, titratable acidity, sugar, alcohol or volatile acidity. In this paper, compositional changes following the addition of flavourings were examined using gas chromatography mass spectrometry (GC-MS). GC-MS is traditionally used for identifying trace amounts of volatile compounds in a mixture which are responsible for aroma and flavour. Interactions between flavour additives and wine compounds continued to evolve with maturation, thus the impact of bottle ageing on the composition and sensory properties of flavoured wines was investigated.

This paper describes a comparison between the composition and sensory profiles of control and flavoured wines after bottling (t=0) and after 12 months of bottle maturation (t=1).

Statement of authorship

Yaelle. Saltman, Julie Culbert, Trent E. Johnson, Renata. Ristic, Kerry L. Wilkinson, Leslie M. Norris, Susan E.P. Bastian (2016).

Impact of bottle aging on the composition and sensory properties of flavoured Chardonnay and Shiraz wines.

Yaelle Saltman

Designed experiments, conducted sensory analysis, analysed and interpreted data, drafted and revised the manuscript. Overall contribution 70%.

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis.

Signed Date 8/11/2016

Julie Culbert

Designed experiments, sample preparation and compositional analysis, analysed and interpreted data, drafted and revised the manuscript.

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis.

Signed Date 8/11/16

Trent Johnson

Assisted with experimental design and the interpretation of data, assisted with revising the manuscript.

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis

Signed. Date 7/11/16

Renata Ristic

Assisted with experimental design and the interpretation of data, assisted with revising the manuscript.

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Signed Date 7/11/16

Kerry Wilkinson

Designed experiments, interpreted sensory and compositional data, drafted and revised the manuscript.

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis.

Signed Date 7/11/16

Susan Bastian

Designed experiments and assisted with the interpretation of data, assisted with revising the manuscript.

I hereby certify that the statement of contribution is accurate and I give permission for inclusion of the paper in this thesis.

Signed Date 7-11-16

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MDPI

Article

Impact of bottle aging on the composition and sensory properties of flavored Chardonnay and Shiraz wines.

Yaelle Saltman, Julie Culbert, Trent Johnson, Renata Ristic, Kerry Wilkinson* and Susan Bastian

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Academic Editor: name
Received: date; Accepted: date; Published: date

Abstract: Natural flavorings can potentially be added to wine to enhance the intensity of desirable aromas and flavors; albeit since flavor additives are not legally permitted winemaking aids, flavored wines must be labelled as wine products. In this study, changes in the composition and sensory profiles of flavored Chardonnay (n=2) and Shiraz (n=2) wines were examined following 12 months bottle aging. Flavorings and flavored wines were analyzed by gas chromatography-mass spectrometry (GC-MS) to identify the key constituents responsible for changes to aroma and flavor profiles. However, many of the volatile compounds identified in flavor additives were not detected at appreciably higher concentrations in flavored wines, which was attributed to the very small quantities of flavorings that were added to base wines. The sensory profiles of control and flavored wines were determined after bottling (t=0), and again after 12 month bottle aging (t=1), by descriptive analysis. The addition of flavorings to base wines significantly influenced wine sensory properties; flavored Chardonnay wines exhibiting enhanced fruit aromas and flavors, while fruit and developed attributes were enhanced in flavored Shiraz wines. Differences in sensory profiles were less apparent in Chardonnay wines following bottle aging but, depending on the flavorings added, flavored Shiraz wines could still be discriminated from their corresponding control wines after aging. Results from this study demonstrate the potential for flavor additives to be used to enhance desirable attributes and/or mitigate wine sensory deficiencies.

Keywords: bottle aging; descriptive analysis; flavor additives; GC-MS; shelf life; wine

1. Introduction

Aroma and flavor intensity are important indicators of wine quality, attributable to the presence of volatile compounds derived from grapes, primary and secondary fermentation, oak maturation and/or aging [1,2], amongst other production practices. The unique combinations of different volatile compounds typically determine wine style and varietal expression [3,4], but wine composition continues to evolve as a consequence of chemical transformations that occur post-bottling [4].

Previous studies have demonstrated the influence of storage conditions, temperature and light exposure in particular, on changes to wine composition during bottle aging [5-8]. The type of packaging and closures used can also influence aging of wine, due to the ingress of oxygen over time [9-11]. Compositional changes due to aging can be either desirable or undesirable. For example, hydrolysis of esters during aging of white wine can result in the loss of varietal expression, i.e. a decrease in the intensity of fruity, floral characters [12,13], while the formation of phenylacetaldehyde and methional due to oxidative effects can give rise to over-ripe fruit or cooked vegetable notes [14]. In some cases however, pleasant toasty, biscuit, honey, nutty and/or toffee characters may form [5,15]. Similarly, hydrolysis of esters can also occur during bottle maturation of red wine, resulting in changes to the profile of volatile compounds present, such that primary fruit characters give way to toasty, caramel, savory, truffle, leather, chocolate, cedar and/or coffee developed notes [16,17]. However, bottle aging of red wine is also associated with modifications in wine color and mouthfeel properties, due to reactions of polyphenolic compounds [18].

Shelf-life is defined as the period of time for which a product remains stable from chemical and/or microbiological transformations that negatively impact its sensory properties [19]. Many of the flavor additives routinely used in food and beverage production, were developed to maintain aroma and flavor integrity, thereby extending shelf-life [20]. Flavor additives are not legally permitted winemaking aids, so their addition to wine renders it a 'wine product'. Nevertheless, a recent study concerning the addition of natural flavorings to wine demonstrated their capacity to improve both the sensory properties and consumer acceptability of wine [21]. For example, flavor additives could be used: (i) to enhance the aroma and/or flavor intensity of wines affected by adverse seasonal conditions; (ii) to mask undesirable green or earthy characters; or (iii) to introduce oak characters to wine, without the investment in time or capital associated with traditional barrel maturation. Despite these potential applications, the stability of flavorings in the acidic wine medium has not yet been investigated. This study therefore sought to determine the impact of bottle aging, together with any shelf-life implications, on the composition and sensory profiles of flavored Chardonnay and Shiraz wines, using a combination of gas chromatography-mass spectrometry (GC-MS) and descriptive analysis, following bottling and (12 months) bottle aging.

2. Materials and Methods

2.1. Flavorings and reagents

Flavor additives were sourced from the Product Makers Pty. Ltd. (Melbourne, Australia; chocolate1039, cinnamon1525, custard1989, orange1883, raspberry228 and vanilla1729) and FlavorSense Corporation (San Rafael, CA, USA; apricotWW3, berry8819, butter10-1206, honey, oak and passion fruit77116). Analytical grade reagents, solvents and standards used in GC-MS analysis were purchased from Sigma Aldrich (NSW, Australia), CDN Isotopes (Pointe-Claire, QC, Canada) and Chem-Supply (Gillman, SA, Australia).

2.2. Preparation and aging of wines

Flavored wines were prepared as described previously [21]. Briefly, four inexpensive commercial wines (retailing at ≤AUD$10 per 750 mL bottle) were sourced from Australian wineries as base wines; with Chardonnay (n=2, CH1 and CH2) and Shiraz (n=2, SH1 and SH2) deliberately chosen as prominent Australian grape varieties. Base wines were spiked with different combinations of flavorings (Table 1) to generate two flavored versions of each base wine. Flavor combinations were selected and optimized based on consumer surveys, bench-top trials and focus panels described elsewhere [21,22]. Following the addition of flavorings, control and flavored wines were bottled (375 mL dark green colored glass bottles) under metal screwcap closures, with minimal ullage (i.e. < 1–2 mL) and carbon dioxide blanketing, and cellared (in an upright position), in darkness at 15°C. Wines were then sampled for chemical and sensory analysis at: t=0, i.e. 5 weeks post-bottling; and t=1, i.e. following 12 months bottle aging.

2.3. Basic wine composition

The pH, titratable acidity (TA, as g/L of tartaric acid) alcohol (% v/v), residual sugar (as g/L of glucose and fructose) and volatile acidity (VA, as g/L of acetic acid) of wines were measured (in duplicate) according to published methodology [23].

Table 1. Flavorings added to Chardonnay and Shiraz base wines.

Wine	Flavor target	Wine code	Flavor additives
CH1	apricot	CH1+A	1.8 g/L apricot[a], 0.6 g/L oak[a], 2.2 g/L butter[a]
	passion fruit	CH1+PF	2.3 g/L passion fruit[a], 2.2 g/L butter[a], 0.5 g/L custard[b]
CH2	honey	CH2+H	1.4 g/L honey[a], 1.5 g/L butter[a], 0.2 g/L vanilla[b]
	passion fruit	CH2+PF	2.2 g/L passion fruit[a], 1.5 g/L butter[a]
SH1	chocolate	SH1+C	3.0 g/L butter[a], 1.0 g/L cinnamon[b], 1.5 g/L orange[b], 2.9 g/L chocolate[b]
	raspberry	SH1+R	3.0 g/L butter[a], 1.6 g/L orange[b], 2.2 g/L custard[b], 0.5 g/L raspberry[a]
SH2	berry	SH2+B	1.7 g/L berry[a], 0.4 g/L custard[b], 1.8 g/L butter[a]
	raspberry	SH2+R	0.5 g/L raspberry[a], 2.1 g/L butter[a]

Flavor additives spiked into base wines as 1% stock solution (20% aqueous ethanol). [a] Flavor additive sourced from FlavorSense Corporation. [b] Flavor additive sourced from The Product Makers.

2.4. Volatile composition of flavorings and wines

2.4.1. Sample preparation

For analysis of flavorings, flavor additives (2–3 drops, approx. 0.1 g) were added to 20 mL screw-cap autosampler vials (Sigma Aldrich), together with Milli-Q water (5 mL) and sodium chloride (2.0 g). Vials were sealed and thoroughly mixed with a vortex mixer prior to GC-MS analysis. For analysis of flavored wines, wine (0.5 mL) was placed in a 20 mL screw-cap autosampler vial containing sodium chloride (2.0 g) and Milli-Q water (4.5 mL) and 2-octanol (10 μL, 50 mg/L in ethanol) added as an internal standard. Vials were sealed and thoroughly mixed using a vortex mixer prior to GC-MS analysis.

2.4.2. GC-MS instrumentation

Samples were analyzed with a 7890A Gas Chromatograph coupled to a 5975C inert XL mass selective detector (Agilent Technologies, Santa Clara, USA) and equipped with a Gerstel MPS2 Multipurpose autosampler (Gerstel, Mülheim an der Ruhr, Germany). Instrument control and data analysis were performed with Agilent ChemStation software and Gerstel MASter software. Samples were incubated with agitation for 10 min at 50°C, prior to headspace solid phase micro-extraction (HS-SPME) for 30 min at 50°C (with agitation) using a Supelco 50/30um DVB/CAR/PDMS 1 cm SPME fiber. The SPME fiber was desorbed in the GC inlet containing an ultra-inert glass SPME liner (straight taper with 0.75 mm i.d.), operating in splitless mode at a temperature of 240°C. The SPME fiber remained in the inlet for 10 min but with a purge flow to split vent of 20 mL/min after 3 min. Separation of volatile compounds was achieved using an Agilent J&W DB-WAXetr capillary column (60 m x 0.25 mm i.d. x 0.25 μm) with ultrapure helium (Coregas, Cavan, Australia) as the carrier gas at a constant flow rate of 1.5 mL/min. The oven program was as follows: 40°C (held for 5 min), increased to 210°C at 2°C/min (held for 5 min), and then to 240°C at 5°C/min (held for 10 min), giving a total runtime of 111 min. The MS was operated using positive ion electron impact at 70 eV in either full scan mode (*m/z* 35-350) or select ion monitoring (SIM), with MS source and quad temperatures of 230°C and 150°C, respectively. The MS transfer line was held at 240°C. SIM parameters were as follows: Group 1 (Start time 0.00 min) *m/z* 43.1, 70.1, 71.1, 86.0, 88.1, 101.1 and 116.1; Group 2 (start time 18.01 min) *m/z* 68.1, 79.1, 93.0 and 136.1; Group 3 (start time 30.00 min) *m/z* 39.1, 41.1, 55.1, 57.1, 67.1, 70.1, 71.1, 82.1, 83.1, 84.1, 89.1, 93.1, 95.0, 96.0, 105.0, 106.0, 121.1, 129.1 and 136.1; Group 4 (start time 48.00 min) *m/z* 59.1, 65.1, 69.1, 91.1, 93.1, 104.1, 121.1, 123.1, 136.1, 138.1, 156.1, 163.0, 164.1 and 192.1; Group 5 (start time of 62.00 min) *m/z* 43.1, 55.1, 57.1, 65.1, 77.1, 85.0, 91.1, 92.1, 93.1, 103.1, 104.1, 121.1, 122.1, 128.1, 131.1, 132.1, 135.1, 136.1, 147.1, 176.1, 177.1 and 192.1. Ions in groups 1 and 2 had a dwell time of 100 ms, while those in groups 3, 4 and 5 had a dwell time of 50 ms. Compound identification was achieved using the NIST 05 Mass Spectral library database and by comparing retention times and mass spectra with those of reference standards (Table S1), when available. Compound peak areas were corrected relative to 2-octanol.

2.5. Sensory analysis of wines

The sensory profiles of control and flavored wines were determined by descriptive analysis (DA). After bottling (i.e. at t=0), DA panels comprising eleven (6 females, 5 males) and twelve (7 females, 5 males) panelists (aged between 22 and 60 years) were assembled to evaluate Chardonnay and Shiraz wines, respectively. Panelists underwent five training sessions (1 x 2 hr session per week, held over 5 consecutive weeks). During training sessions, the panel evaluated the aroma, flavor, taste and mouthfeel attributes of wines, according to standard DA protocol [24] and were introduced to the tasting booths in which formal evaluations would be held (i.e. under controlled ventilation, light conditions, and temperature, being 22–23°C). The Chardonnay DA panel generated nine aroma, five flavor, and five taste and mouthfeel descriptors; while the Shiraz DA panel identified eight aroma, six flavor, and five taste and mouthfeel descriptors (Table 2). Reference standards were developed during early training sessions and were freshly prepared (in covered, opaque black glasses) for use at subsequent training sessions and throughout formal evaluations. During training, panelists practiced rating the intensity of each descriptor. Examples of taste and mouthfeel attributes (from low to high) were also provided and comprised creaminess (low fat milk to full cream milk), acidity (base wine spiked with 0.5 to 2 g/L tartaric acid), bitterness (base wine spiked with 5 to 20 mg/L quinine sulfate), and astringency (felt material to sandpaper). Aftertaste was defined as the length of time for which fruit and/or phenolic attributes were perceived after expectoration.

After 12 months bottle aging (i.e. at t=1), DA panels were again assembled. The Chardonnay DA panel comprised twelve panelists (7 females, 5 males), eleven of whom participated at t=0; the Shiraz DA panel also comprised twelve panelists (7 females, 5 males), all of whom participated at t=0. Both panels were re-trained as described above. However, the DA panels identified and rated several additional descriptors in Chardonnay and Shiraz wines, at t=1 (Table 2).

Formal evaluations commenced once panel performance was considered to be satisfactory (based on panel by sample interactions). At each time point (i.e. t=0 and t=1), two formal evaluation sessions were held, with 12 wines presented per session, such that four replicates of each wine were assessed. Wines (30 mL) were assigned random three digit codes and served in XL5 (ISO standard) 215 mL wine glasses covered with plastic lids, using a randomized presentation order, with wines presented in brackets of six. Chardonnay wines were served at 14–16°C and Shiraz wines were served at 22–24°C. Panelists evaluated wines and recorded the intensity of each sensory attribute using FIZZ data acquisition software (Version 2.47b, Biosystèms, Couternon, France) on 15 cm unstructured line scales with anchor points of 'low' and 'high' placed at 0% and 100% on the scale, respectively. Between each sample, panelists cleansed their palate with filtered water and unsalted crackers during a one minute break. Panelists were required to have five minute breaks after each bracket. All samples were expectorated.

Table 2. Attributes and standards used in descriptive analysis of Chardonnay and Shiraz wines.

Attribute	Reference standard
White wine descriptors	
passion fruit	4 drops passion fruit flavor additive[a]
tropical fruit	1 cm cube each of paw paw + pineapple + mango + melon
stone fruit	1 cm cube each of white peach + nectarine, 4 drops apricot flavor additive[a]
citrus	1 cm cube each of mandarin + lemon + orange
green	0.15 g freshly cut grass
honey	½ tbsp of honey (Capilano)
vanilla	3 drops vanilla flavor additive[b]
butter	5 drops butter flavor additive[b]
orange blossom	0.3 g freshly cut leaves from an orange tree
mixed spice	¼ tsp of allspice (McKenzies) + 4 drops cinnamon flavor additive[b]
caramel lolly	1 caramel lolly (Coles brand) cut into small pieces
oak	0.07 g medium toasted American oak chips (O.C. Inc.)
dried stone fruit[c]	½ dried apricot + ½ dried peach cut into small pieces
melon[c]	1 cm cube of honeydew melon
toast[c]	2 toasted almonds crushed (Woolworths Select)
green vegetable[c]	1 cm cube of green apple + green capsicum
Red wine descriptors	
red berry	2 frozen raspberries + 1 frozen strawberry (McCains)
dark berry	5 drops blackcurrant flavor additive[b] + 6 drops blackberry flavor additive[b]
confectionary	6 drops raspberry flavor additive[a] + 6 drops berry flavor additive[a]
chocolate-vanilla	3 drops vanilla flavor additive[b] + 10 drops chocolate flavor additive[b]
mixed spice	6 drops cinnamon flavor additive[b]
earthy	30 g wet earth
green	2 frozen blackcurrants + 1 frozen blackberry (McCains)
black pepper	0.02 g black pepper (McCormick)
oak	0.07 g medium toasted American oak chips (O.C. Inc.)
plum[c]	1 plum (20 g) cut into small pieces (Coles brand)
licorice[c]	licorice (6 g) cut into small pieces (Coles brand)
dried herbs[c]	0.02 g oregano (McCormick) + 0.02 g thyme (McCormick)
cherry[c]	1 pitted sour cherry (3–5 g) (Always Fresh)
green vegetable	1 cm cube of green apple + green capsicum
Mouthfeel descriptors	
bitterness	quinine sulfate (low 5mg/L – high 20 mg/L)
acidity	tartaric acid (low 0.5 g/L – high 2g/L)
astringency	felt material (low) – sandpaper (high)
creaminess	low fat milk (low) to full cream milk (high)

Standards were prepared in 30 mL of unoaked Chardonnay or Shiraz cask wine. Flavor additives spiked into reference standards as 1% stock solution (20% aqueous ethanol). [a]Flavor additives sourced from FlavorSense Corporation. [b]Flavor additives sourced from The Product Makers. [c]Attributes associated with bottle ageing (i.e. t=1 wines).

2.6. Data analysis

Data were analyzed using: XLSTAT (version 2011.5.01, Addinsoft) for one-way analysis of variance (ANOVA), where mean comparisons were performed by Fisher's least significant difference (LSD) post hoc test at $P<0.05$; and SENPAQ (version 5.01, Qi Statistics, Reading, UK) for principal component analysis (PCA).

2.7. Ethical Statement

DA panelists gave informed consent before they participated in the study. The study was approved by the Human Research Ethics Committee of The University of Adelaide (Project No. H-174-2011).

3. Results and Discussion

3.1. Influence of flavoring and aging on basic wine composition

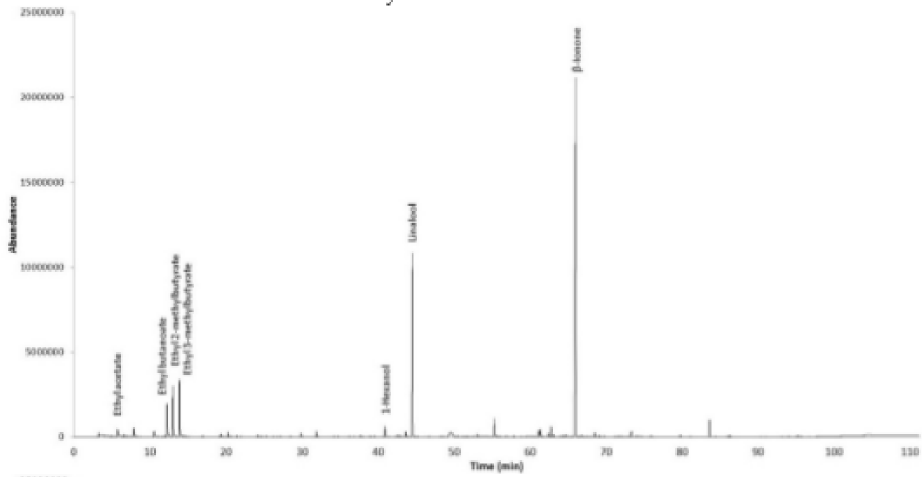
Standard wine analyses, i.e. determinations of pH, TA, alcohol, residual sugar and VA, were performed on control and flavored Chardonnay and Shiraz wines following bottling (t=0) and 12 months bottle aging (t=1), in order to investigate compositional differences amongst wines attributable to either the addition of natural flavorings or bottle aging (Table S2). As expected, compositional differences were observed between base wines, but no significant differences were observed between control wines and their corresponding flavored wines, or between wines after bottling and bottle aging (i.e. at t=0 and t=1); i.e. neither the addition of natural flavorings nor bottle aging significantly influenced basic wine composition.

3.2 Volatile composition of flavor additives and flavored wines

The composition of flavor additives were analyzed by GC-MS in an attempt to identify the key volatile compounds responsible for their characteristic aromas and flavors. The complexity of flavorings varied considerably, with some flavor additives comprising relatively few volatile compounds, e.g. the raspberry flavor additive (Figure 1a), while others contained an array of constituents; around 20, in the case of the passion fruit flavoring (Figure 1b). The key constituents of flavorings predominantly comprised isoprenoids, furans, esters, alcohols and volatile phenols (Table 3); all of which have previously been identified as constituents of grapes and/or wine [25-27].

Control and flavored wines were also analyzed by GC-MS (at both t=0 and t=1), to determine compositional changes attributable to the addition of flavorings and/or bottle aging. However, flavorings were added to wines in such small quantities, i.e. as 1% solutions prepared from ≤ 3.0 g/L standards of flavor additives (Table 1), that many of the volatile compounds identified as constituents of flavor additives were either not detected in flavored wines or were present at similar concentrations to those of corresponding control wines (data not shown); irrespective of whether samples were analyzed using full scan mode or following development of SIM methods to improve selectivity and sensitivity. However, there were some notable exceptions (Table 4). Similar levels of *cis*-3-hexenyl butyrate were found in CH1 and CH1+PF at t=0, but almost 30-fold higher concentrations were observed in CH1+PF, than in CH1, at t=1. Comparable results were obtained following the addition of passion fruit flavoring to CH2; approximately 50-fold higher *cis*-3-hexenyl butyrate concentrations were found in CH2+PF, than in CH2 at t=1. Although similar levels of linalool were found in CH1 and CH1+PF at t=0, CH1+PF contained approximately double the linalool content of CH1 at t=1. The linalool and limonene concentrations of SH1+C and SH1+R were similarly found to increase (relative to SH1) following bottle aging. Significant quantities of 2-ethyl hexanol were detected in all control and flavored SH1 wines; levels were higher in SH1+C than SH1 at t=0, but lower in SH1+C (than SH1) at t=1. The addition of berry flavoring to SH2 resulted in significantly higher concentrations of linalool and α- and β-ionone in SH2+B (approximately 55%, 1,900% and 360% higher levels, respectively, at t=0). Linalool levels remained similar for control and flavored SH2 wines following bottle aging, but the α- and β-ionone content of SH2-B increased (by an additional 50–100%) during bottle aging. Approximately two-fold higher concentrations of phenethyl acetate were found in CH2+H than in CH2. In some instances, compositional differences between control and flavored wines were directly attributable to the addition of flavor additives, but changes observed after bottle aging likely reflect chemical transformations of wine and/or flavor constituents [4].The detection of volatile compounds derived from flavor additives could be improved through various method development strategies, for example, through extraction of larger volumes of flavored wine, different sampling methods and/or the use of more specific standards (i.e. isotopically labelled internal standards). In this study, the impact of flavor addition and bottle aging was instead assessed via sensory analysis. However, it should be acknowledged that challenges associated with detecting flavor constituents in wine have implications for policing the use of flavor additives by industry; i.e. where their use is legally prohibited, flavorings can seemingly impact wine aroma and flavor at concentrations that cannot be readily detected.

a)



b)

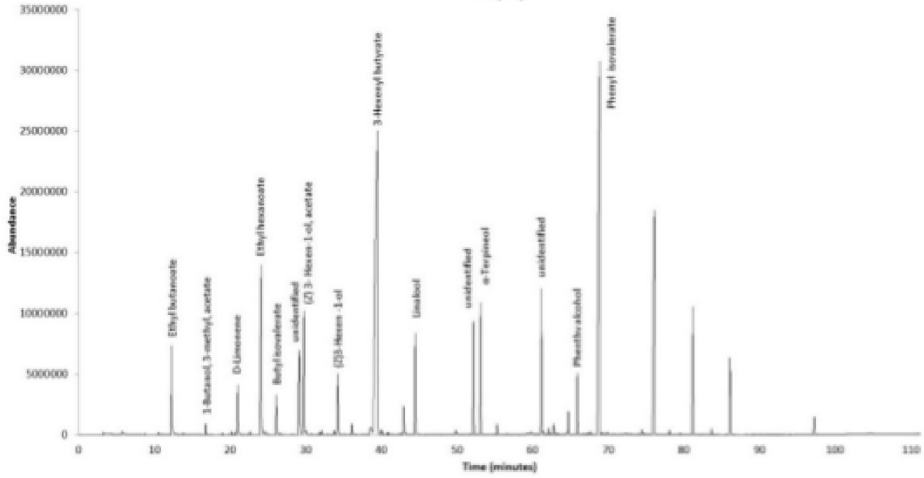


Figure 1. Chromatograms of a) raspberry and b) passion fruit flavor additives.

Table 3. Key volatiles identified as constituents of natural flavor additives as determined by GC-MS.

Flavor additives	Volatile compounds
apricot	linalool, hexyl butanoate
berry	linalool, α-terpineol, α-ionone
butter	ethyl butanoate
chocolate	2-ethyl-1-hexanol, ethyl butanoate
cinnamon	cinnamaldehyde, ethyl cinnamate, benzaldehyde
custard	ethyl butanoate
honey	2-phenylethyl acetate, ethyl acetate
oak	2-phenylethyl alcohol, furfural
orange	linalool; ethyl butanoate, limonene
passion fruit	2-phenethyl isovalerate, *cis*-3-hexenyl butyrate
raspberry	β-ionone, linalool
vanilla	vanillin, 2-ethyl 1-hexanol

Table 4. Peak areas for selected volatile constituents of control and flavoured Chardonnay and Shiraz wines, following bottling (t=0) and 12 months aging (t=1).

Flavor target	Compound	Wine composition	
berry	linalool	SH2 (t=0): 77,936 SH2+B (t=0): 120,887	SH2 (t=1): 74,909 SH2+B (t=1): 110,252
	α-ionone	SH2 (t=0): 1,797 SH2+B (t=0): 35,769	SH2 (t=1): 1,842 SH2+B (t=1): 53,500
	β-ionone	SH2 (t=0): 2,686 SH2+B (t=0): 12,429	SH2 (t=1): 2,416 SH2+B (t=1): 27,276
chocolate	2-ethyl-1-hexanol	SH1 (t=0): 693,470 SH1+C (t=0): 880,936	SH1 (t=1): 903,129 SH1+C (t=1): 783,384
	linalool	SH1 (t=0): 65,153 SH1+C (t=0): 67,702	SH1 (t=1): 66,725 SH1+C (t=1): 430,975
	limonene	SH1 (t=0): 14,347 SH1+C (t=0): 18,966	SH1 (t=1): 18,458 SH1+C (t=1): 50,955
honey	2-phenylethyl acetate	CH2 (t=0): 327,217 CH2+H (t=0): 734,763	CH2 (t=1): 325,031 CH2+H (t=1): 511,441
passion fruit	*cis*-3-hexenyl butyrate	CH1 (t=0): 4,309 CH1+PF (t=0): 3,232	CH1 (t=1): 3,272 CH1+PF (t=1): 87,350
		CH2 (t=0): 3,531 CH2+PF (t=0): 2,990	CH2 (t=1): 3,400 CH2+PF (t=1): 161,211
	linalool	CH1 (t=0): 46,231 CH1+PF (t=0): 43,152	CH1 (t=1): 45,623 CH1+PF (t=1): 95,449
raspberry	linalool	SH1 (t=0): 65,153 SH1+R (t=0): 62,545	SH1 (t=1): 66,725 SH1+R (t=1): 282,633
	limonene	SH1 (t=0): 14,347 SH1+R (t=0): 19,719	SH1 (t=1): 18,458 SH1+R (t=1): 41,333

Peak areas were corrected against the internal standard (i.e. 2-octanol).

3.2. Sensory profiles of control and flavored wines

Descriptive analysis was performed on control and flavored Chardonnay and Shiraz wines at both t=0 and t=1, to determine the impact of flavor addition and bottle aging on wine sensory profiles (Tables 5–8). PCA was subsequently performed on sensory data (Figures 2–5), with the first two principal components explaining between 88 and 94% of variation amongst wine sensory profiles. As previously reported, the addition of flavorings markedly influenced the sensory profiles of Chardonnay and Shiraz wines [21], but bottle aging also influenced wine aroma, flavor and mouthfeel attributes.

The addition of apricot and passion fruit flavorings to CH1 enhanced the intensity of selected fruit and/or floral characters, and diminished astringency (Table 5). As a consequence, CH1+A and CH1+PF clustered well away from CH1 at t=0 (Figure 2). However, after 12 months bottle aging, differences between control and flavored wines were less apparent; with the intensity of sensory attributes increasing significantly, for CH1, CH1+A and CH1+PF alike. This likely reflects the development of some complexity due to aging, i.e. increases in the intensity of vanilla, butter, mixed spice, caramel and oak characters, as well as the occurrence of dried fruit, toast and green notes (Table 5). However, it should be acknowledged that this might also reflect differences in the composition and/or performance of the DA panel between t=0 and t=1. LSD values were higher at t=1 compared to t=0, despite the panel undergoing training at both time points. Increased LSD values could also reflect the panel's broader use of the intensity scales. Regardless, the PCA biplot of sensory data clearly demonstrates the impact of flavor addition was more apparent at t=0; i.e. at t=1, control and flavored Chardonnay 1 wines were clustered in much closer proximity to one another, than at t=0 (Figure 2).

Table 5. Mean intensity ratings for aroma, flavor, taste and mouthfeel attributes of control and flavored Chardonnay 1 wines following bottling (t=0) and 12 months aging (t=1).

Attributes	CH1 t=0	CH1+A t=0	CH1+PF t=0	LSD t=0	CH1 t=1	CH1+A t=1	CH1+PF t=1	LSD t=1	LSD t=0 x t=1
A Passion fruit	7.4	7.4	8.9	1.6	10.2	11.8	10.4	2.2	2.1
A Tropical fruit	8.6	9.8	9.7	1.5	9.5	9.4	9.0	2.7	1.6
A Stone fruit	7.3 b	9.1 a	9.6 a	1.7	8.5	10.3	9.2	2.6	2.6
A Citrus	3.6 b	6.3 a	5.8 a	1.6	6.7	6.3	5.9	2.6	2.1
A Green	2.3	1.9	2.0	1.2	2.9 a	1.5 ab	1.0 b	1.7	1.4
A Honey	5.1	5.3	4.1	1.8	7.7	9.6	8.7	2.5	2.0
A Vanilla	4.4	4.4	4.5	1.7	7.5 b	10.5 a	8.1 ab	2.7	1.6
A Butter	3.8 a	3.2 ab	2.1 b	1.5	8.0	9.3	8.6	2.8	2.2
A Orange blossom	3.1 b	5.7 a	4.0 b	1.6	7.5	8.3	8.1	2.6	2.0
A Dried stone fruit[a]	–	–	–	–	8.5	10.6	10.3	2.7	–
A Melon[a]	–	–	–	–	4.0	5.3	6.5	2.7	–
A Toast[a]	–	–	–	–	6.4	6.9	5.8	2.8	–
F Passion fruit	9.5	9.2	9.2	1.4	11.1	10.6	9.6	2.7	1.7
F Stone fruit	9.0	9.5	9.6	1.5	10.2	9.4	10.1	2.3	1.9
F Mixed spice	4.6 ab	5.9 a	3.6 b	1.4	8.8	8.2	8.8	2.7	2.4
F Caramel lolly	4.3 ab	5.3 a	3.7 b	1.4	6.8 b	10.0 a	9.5 a	2.5	2.3
F Oak	3.3 b	4.8 a	3.3 b	1.3	8.7	9.9	9.1	2.7	2.1
F Dried stone fruit[a]	–	–	–	–	10.0 b	12.5 a	11.7 ab	2.2	–
F Green vegetable[a]	–	–	–	–	3.1	1.9	2.7	2.1	–
Bitterness	5.5	5.6	5.2	1.6	6.4	6.9	6.0	2.6	2.4
Acidity	8.0	7.9	8.3	1.6	9.0	9.7	8.9	2.2	1.9
Astringency	6.1 a	3.9 b	4.9 b	1.3	8.4	7.1	7.2	2.3	1.8
Creaminess	5.8 a	3.8 b	4.0 b	1.3	6.3 b	9.5 a	7.5 ab	2.5	1.7
Aftertaste	10.9 a	6.4 b	7.1 b	1.7	10.0	10.8	10.1	1.7	1.4

Values are mean scores from 4 replicates per treatment, determined by 11 judges at t=0 and 12 judges at t=1. Mean values followed by a different letter within a row (by treatment for each time point) are significantly different ($p \leq 0.05$, one way ANOVA, Fisher's LSD post hoc). A: aroma attribute, F: flavor attribute. [a] Attributes associated with aged wines only.

Less favorable results were achieved following addition of flavor additives to Chardonnay 2. The honey flavoring had little impact on wine aroma or flavor (Table 6), such that CH2+H was located quite close to CH2 at t=0 (Figure 3); while the addition of passion fruit flavoring surprisingly resulted in less intense fruit characters and more prominent bitterness, acidity and astringency (Table 6). CH2+PF was therefore positioned away from both CH2 and CH2+H at t=0 (Figure 3). The increased bitterness, acidity and astringency perceived in CH2+PF may reflect cross-modal interactions [28]. Previous studies have shown certain aromas can enhance taste perceptions without directly imparting taste properties [29,30]. Certainly in the current study, the enhanced acidity perceived in CH2+PF at t=0 was not indicative of any significant differences in pH or TA (Table S2).

Table 6. Mean intensity ratings for aroma, flavor, taste and mouthfeel attributes of control and flavored Chardonnay 2 wines following bottling (t=0) and 12 months aging (t=1).

Attributes	CH2 t=0	CH2+H t=0	CH2+PF t=0	LSD t=0	CH2 t=1	CH2+H t=1	CH2+PF t=1	LSD t=1	LSD t=0 x t=1
A Passion fruit	10.0 a	9.5 a	7.6 b	1.8	11.7	10.4	11.3	2.1	1.9
A Tropical fruit	10.5	10.5	10.1	1.8	10.2	8.8	10.8	2.5	1.8
A Stone fruit	6.5 ab	8.2 a	6.0 b	2.0	8.0 b	8.9 ab	10.8 a	2.5	1.6
A Citrus	6.2 a	3.3 b	2.6 b	1.4	7.7	7.1	8.7	2.8	1.8
A Green	1.7	1.0	1.0	0.8	3.3	2.1	3.0	2.2	1.4
A Honey	5.1 ab	5.2a	3.2 b	2.0	6.1 b	9.5 a	7.3 ab	2.7	2.4
A Vanilla	5.5	4.1	5.3	2.0	7.0	8.9	6.5	2.9	2.4
A Butter	3.5 a	2.9 ab	1.7 b	1.5	8.1	8.0	7.6	2.9	2.0
A Orange blossom	2.4	2.1	2.7	1.1	7.3	8.1	9.3	2.6	1.6
A Dried stone fruit[a]	–	–	–	–	8.4	10.2	8.3	2.8	–
A Melon[a]	–	–	–	–	5.6	5.6	6.1	2.7	–
A Toast[a]	–	–	–	–	5.2	6.6	4.5	2.8	–
F Passion fruit	9.8	10.8	9.5	1.6	12.0	10.1	12.1	2.1	1.6
F Stone fruit	7.7	8.8	7.1	1.8	10.0	9.6	11.6	2.4	1.7
F Mixed spice	2.5 b	3.3 b	2.4 b	1.4	5.7	6.3	7.0	2.7	1.9
F Caramel lolly	3.1	3.5	3.2	1.4	6.2	9.0	7.0	2.7	2.2
F Oak	2.3 b	3.7 a	2.9 ab	1.2	6.6 b	9.3 a	6.0 b	2.7	2.2
F Dried stone fruit[a]	–	–	–	–	9.6	11.0	9.9	2.6	–
F Green vegetable[a]	–	–	–	–	3.5	2.0	4.1	2.4	–
Bitterness	3.0 c	5.3 b	9.7 a	1.8	6.1	4.8	4.9	2.3	1.9
Acidity	7.2 b	6.7 b	11.2 a	1.7	10.0	9.8	11.3	2.0	1.9
Astringency	5.4 b	5.0 b	9.3 a	1.4	6.6	6.6	7.4	2.5	2.0
Creaminess	7.3 ab	6.4 b	8.5 a	1.6	7.2	7.8	6.3	2.6	1.9
Aftertaste	7.9 b	9.6 ab	10.7 a	1.4	8.9 b	11.2 a	10.0 ab	1.8	1.5

Values are mean scores from 4 replicates per treatment, determined by 11 judges at t=0 and 12 judges at t=1. Mean values followed by a different letter within a row (by treatment for each time point) are significantly different ($p \leq 0.05$, one way ANOVA, Fisher's LSD post hoc). A: aroma attribute, F: flavor attribute. [a] Attributes associated with aged wines only.

Bottle aging of CH2 gave a similar outcome to that observed for CH1; i.e. significantly enhanced vanilla, butter, orange blossom, mixed spice, caramel lolly and oak characters, together with dried fruit, toast and green vegetable notes (Table 6). Interestingly, the bitterness, acidity and astringency observed in CH2+PF at t=0 were no longer prominent following bottle aging. Indeed, at t=1, control and flavored Chardonnay 2 wines had relatively similar sensory profiles, albeit CH2+H exhibited more intense honey and oak notes, than CH2 (at t=1). This resulted in the differences observed amongst Chardonnay 2 wines at t=0 being far less apparent at t=1, such that wines were closely clustered at t=1 (Figure 3). Again, the evolution of additional attributes, dried fruit and toast in particular (Table 6), was consistent with the developed notes associated with bottle age in white wine.

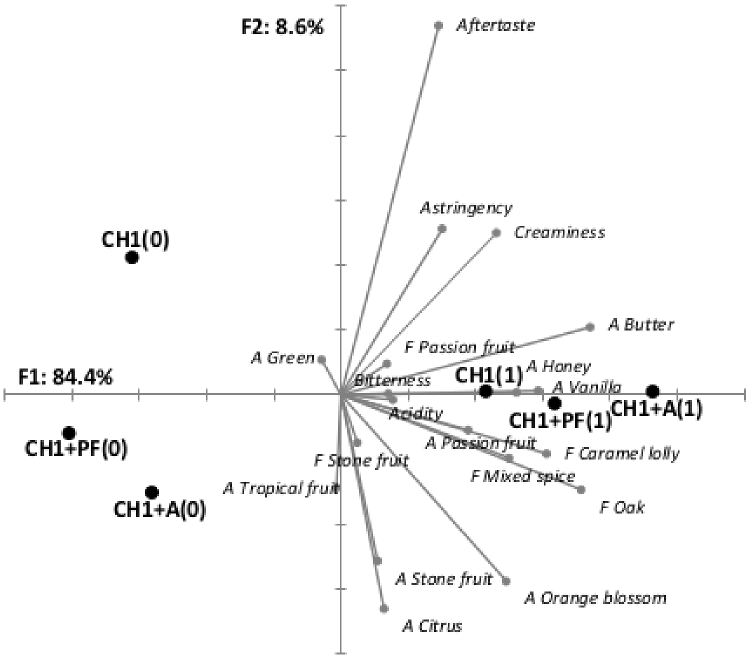


Figure 2. PCA biplots of sensory attributes for control and flavored Chardonnay 1 wines following bottling (t=0) and 12 months bottle aging (t=1).

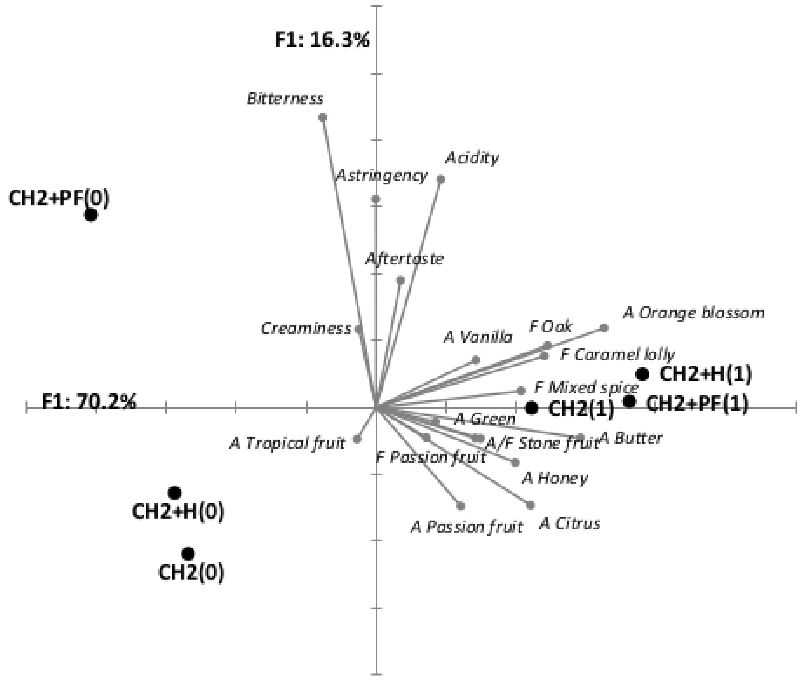


Figure 3. PCA biplots of sensory attributes for control and flavored Chardonnay 2 wines following bottling (t=0) and 12 months bottle aging (t=1).

Table 7. Mean intensity ratings for aroma, flavor, taste and mouthfeel attributes of control and flavored Shiraz 1 wines following bottling (t=0) and 12 months aging (t=1).

Attributes	SH1 t=0	SH1+C t=0	SH1+R t=0	LSD t=0	SH1 t=1	SH1+C t=1	SH1+R t=1	LSD t=1	LSD t=0 x t=1
A Red berry	5.2	6.4	6.1	1.9	4.9	6.2	5.0	1.6	1.7
A Dark berry	7.7	8.1	7.6	1.7	6.9	6.4	7.1	1.5	1.8
A Confectionary	5.4 b	5.8 b	8.3 a	1.9	3.6 b	4.6 b	6.5 a	1.7	1.8
A Chocolate-vanilla	5.4 b	5.3 b	8.4 a	1.7	4.7 b	4.8 b	7.8 a	1.6	1.7
A Mixed spice	6.4	6.1	5.5	1.5	4.4	4.8	4.9	1.7	1.2
A Earthy	2.2 ab	3.0 a	1.7 b	1.2	4.8	3.5	4.2	1.7	1.5
A Green	2.1	2.8	1.6	1.2	4.6 a	3.4 ab	2.5 b	1.6	1.3
A Black pepper	4.8	5.2	4.6	1.7	5.7	4.8	4.3	1.7	1.2
A Plum[a]	–	–	–	–	5.2	4.8	4.9	1.7	–
A Licorice[a]	–	–	–	–	4.1	4.0	4.0	1.6	–
A Dried herbs[a]	–	–	–	–	3.5	3.0	3.5	1.7	–
F Red berry	6.7	6.4	7.0	1.8	6.5	6.3	6.7	1.4	1.5
F Dark berry	9.2	8.7	9.3	1.4	7.7	7.1	7.2	1.3	1.4
F Confectionary	5.2 ab	4.8 b	6.6 a	1.7	4.4 b	5.1 ab	6.5 a	1.7	1.6
F Mixed spice	6.5	6.0	6.3	1.6	5.2	4.7	6.0	1.6	1.5
F Chocolate-vanilla	4.2 b	3.9 b	6.4 a	1.5	5.0 b	5.2 b	7.1 a	1.5	1.6
F Oak	7.4	7.0	7.9	1.5	5.8	5.6	6.8	1.4	1.4
F Cherry[a]	–	–	–	–	6.4 a	4.8 b	6.8 a	1.5	–
F Green vegetable[a]	–	–	–	–	4.2	3.4	2.8	1.5	–
Bitterness	6.5	6.1	5.2	1.7	5.9	6.3	4.8	1.5	1.3
Acidity	7.4	7.9	7.5	1.6	6.0	6.0	6.2	1.5	1.1
Astringency	7.9	7.8	8.4	1.4	7.8	8.3	7.5	0.9	0.9
Alcohol	8.4	7.7	7.7	1.3	7.3	7.4	6.6	1.0	1.1
Length	10.6	10.4	10.9	1.5	7.0	7.1	7.5	0.9	1.1

Values are mean scores from 4 replicates per treatment, determined by 12 judges at t=0 and 12 judges at t=1. Mean values followed by a different letter within a row (by treatment for each time point) are significantly different ($p \leq 0.05$, one way ANOVA, Fisher's LSD post hoc). A: aroma attribute, F: flavor attribute. [a] Attributes associated with aged wines only.

The addition of flavorings to SH1 significantly increased the perception of confectionary and chocolate-vanilla characters, and diminished the earthy aroma of SH1+R, but sensory differences between SH1 and SH1+C were not statistically significant (Table 7). This was surprising given the chocolate flavoring was intended to enhance chocolate notes, i.e. so as to mimic oak characters. In the case of SH1+R, this was attributed to the butter and custard flavor additives present in the raspberry flavoring. This combination of flavors (i.e. butter, orange, custard and raspberry) maintained its influence on wine aroma and flavor during bottle aging, with confectionary and chocolate-vanilla characters still significantly different at t=1. Again, additional attributes were observed at t=1, i.e. plum, licorice, dried herbs, cherry and green vegetable aromas or flavors, due to aging (Table 7). SH1 and SH1+C were closely positioned on the PCA biplot at both t=0 and t=1 (Figure 4), reflecting their similar sensory profiles. In contrast, SH1+R was clearly separated at both time points, largely due to enhanced confectionary and chocolate-vanilla aroma and flavor. This suggests the raspberry flavoring added to SH1 had greater persistence than the flavorings added to Chardonnay base wines.

The berry flavoring, which comprised berry, custard and butter flavor additives, enhanced the confectionary, chocolate-vanilla and red berry characters of SH2, and diminished the intensity of oak flavor (Table 8), whereas the raspberry flavoring did not significantly influence wine aroma or flavor (at either t=0 or t=1). SH2 and SH2+R were therefore positioned close together in the lower quadrants of the PCA biplot (at both time points), while SH2+B was located in the upper quadrants (Figure 5), reflecting its more prominent confectionary and red berry aromas and flavors.

Table 8. Mean intensity ratings for aroma, flavor, taste and mouthfeel attributes of control and flavored Shiraz 2 wines following bottling (t=0) and 12 months aging (t=1).

Attributes	SH2 t=0	SH2+B t=0	SH2+R t=0	LSD t=0	SH2 t=1	SH2+B t=1	SH2+R t=1	LSD t=1	LSD t=0 x t=1
A Red berry	6.3	7.0	6.8	1.9	5.4 b	7.7 a	6.2 ab	1.5	1.6
A Dark berry	7.9	7.7	8.4	1.8	6.0	6.6	7.1	1.6	1.2
A Confectionary	6.4	8.0	6.7	1.9	4.1 b	6.4 a	5.0 ab	1.6	1.4
A Chocolate-vanilla	4.6	5.3	4.9	1.5	3.9	5.2	4.4	1.7	1.5
A Mixed spice	6.0	5.5	5.6	1.7	3.6	3.7	4.9	1.7	1.3
A Earthy	2.3	2.7	2.1	1.3	4.7	3.0	4.2	1.7	1.8
A Green	2.4	2.6	2.8	1.3	4.5	4.0	3.6	1.7	1.3
A Black pepper	5.2	4.7	4.8	1.7	4.3	5.3	4.5	1.7	1.2
A Plum[a]	–	–	–	–	5.4	4.8	6.0	1.7	–
A Licorice[a]	–	–	–	–	4.6	5.0	4.1	1.7	–
A Dried herbs[a]	–	–	–	–	3.1	2.9	2.9	1.6	–
F Red berry	7.5	8.7	7.8	1.8	7.3	8.2	7.7	1.1	1.2
F Dark berry	9.2	9.8	9.7	1.5	7.4	7.6	7.4	1.2	1.2
F Confectionary	7.5 ab	8.8 a	6.7 b	1.7	6.6	7.1	7.1	1.3	1.4
F Mixed spice	5.4	5.4	5.5	1.5	4.1	5.2	5.3	1.6	1.1
F Chocolate-vanilla	4.8	5.5	4.4	1.5	4.3	5.8	4.9	1.5	1.5
F Oak	8.2 a	6.2 b	7.6 ab	1.5	4.9	4.9	4.9	1.5	1.1
F Cherry[a]	–	–	–	–	6.7	6.9	4.9	1.4	–
F Green vegetable[a]	–	–	–	–	3.7	3.7	2.9	1.5	–
Bitterness	5.3	4.6	5.0	1.5	5.3	4.4	4.4	1.5	1.4
Acidity	6.8	7.3	7.3	1.5	6.2	5.8	6.4	1.3	1.2
Astringency	7.9	7.9	7.9	1.4	7.0	6.0	6.6	1.3	1.4
Alcohol	7.1	8.1	7.9	1.3	6.7	6.4	6.9	1.0	1.2
Length	9.8	10.3	10.1	1.7	7.1	7.5	7.4	0.9	1.2

Values are mean scores from 4 replicates per treatment, determined by 12 judges at t=0 and 12 judges at t=1. Mean values followed by a different letter within a row (by treatment for each time point) are significantly different ($p \leq 0.05$, one way ANOVA, Fisher's LSD post hoc). A: aroma attribute, F: flavor attribute. [a] Attributes associated with aged wines only.

A key aim of this study was to determine the impact of bottle aging on the sensory profiles of flavored Chardonnay and Shiraz wines. Collectively, the PCA biplots provide a graphical representation of the influence of flavor additives and bottle aging on wine sensory properties. (Figures 2–5). In most, but not all cases, the modification to wine aroma and flavor following the addition of flavorings resulted in flavored wines being positioned separate to their corresponding control wines; with the degree of separation determined by the extent to which flavorings impacted wine sensory properties. However, where flavorings had only limited impact on wine sensory profiles, the addition of more concentrated flavorings, or flavorings comprised of different combinations of flavor additives, could achieve more apparent sensory outcomes. Regardless, bottle aging seemingly influenced flavored Chardonnay and Shiraz wines differently. The differences observed between the sensory profiles of control and flavored Chardonnay wines after bottling (i.e. at t=0) were not as apparent after 12 month bottle aging (i.e. at t=1). Chardonnay wines were clustered relatively close together (Figures 2 and 3), which may have reflected the development of some secondary vanilla, butter, spice, caramel and/or honey characters in control wines. In contrast, differences observed between control and flavored Shiraz wines persisted during bottle aging, such that the sensory impact of flavor additives on wine aroma and/or flavor were still apparent (Figures 4 and 5). These results suggest that flavorings could be used to influence the sensory profiles of wines over the long-term, with optimization of the concentration and composition of flavorings used enabling improved sensory outcomes to be realized.

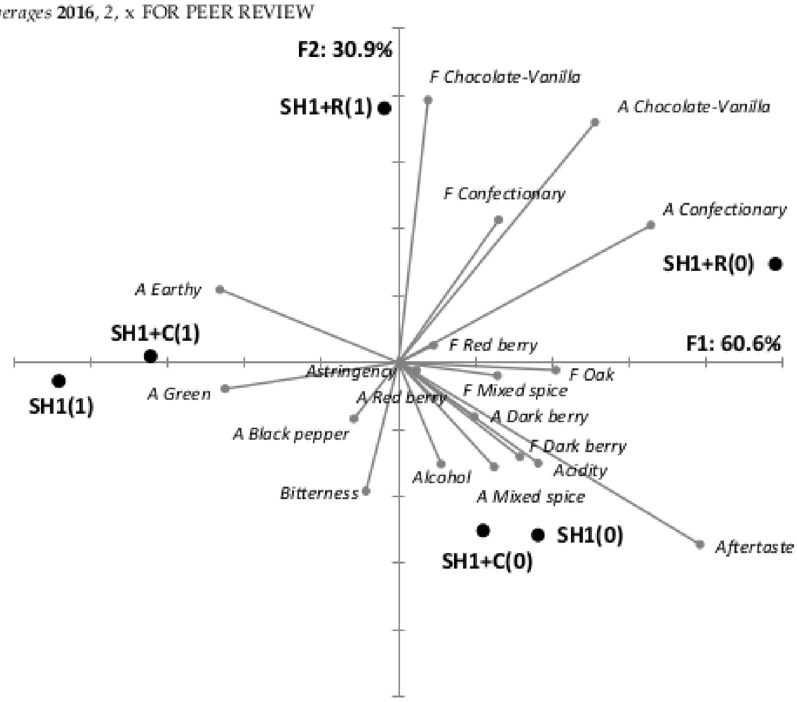


Figure 4. PCA biplots of sensory attributes for control and flavored Shiraz 1 wines following bottling (t=0) and 12 months bottle aging (t=1)

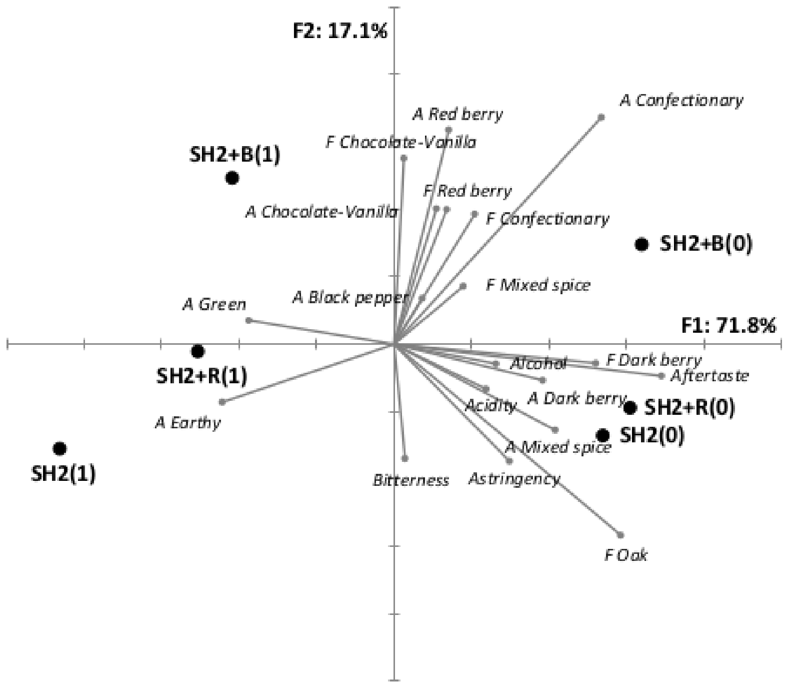


Figure 5. PCA biplots of sensory attributes for control and flavored Shiraz 2 wines following bottling (t=0) and 12 months bottle aging (t=1).

Although flavor additives are routinely used in many food and beverage industries, they are not legally permitted winemaking aids [31] and so their use in wine production is currently prohibited. It is unlikely that flavorings would ever be used in the production of premium quality wines, for which winemakers and consumers alike value traditional approaches to winemaking. However, this study demonstrates the potential for flavorings to mitigate sensory deficiencies in lower quality and/or commodity wines, should the regulations governing winemaking additives ever be reviewed. Findings could also be applied in the production of wine products, i.e. wines made with the addition of flavorings, legally defined (in Australia) as 'a food containing no less than 700 mL/L of wine which has been formulated, processed, modified or mixed with other foods' [31].

As indicated above, differences in the composition and/or performance of the DA panel between t=0 and t=1 are acknowledged as an inherent limitation of the study. The differences observed in the sensory profiles of control and flavored wines between time points may, in part, have been attributable to the DA panel. Nonetheless, significant differences were still observed between the sensory properties of control and flavored wines at each time point. The DA panels identified several new attributes in bottle aged wines, some of which were consistent with descriptors associated with bottle aging, i.e. dried fruit and toast for white wine and licorice and plum for red wine. Most importantly, there was no evidence to suggest that any chemical transformation of natural flavorings that might have occurred resulted in the formation of off-odors during bottle aging; i.e. at t=1, the flavor additives had not negatively impacted wine sensory profiles.

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4. Conclusions

The natural flavorings used in this study were found to contain volatile compounds previously identified in grapes and/or wine, but their addition to base wines did not always significantly impact wine composition; i.e. many of the volatile compounds identified as constituents of flavor additives were not detected at appreciably higher concentrations in flavored wines, which likely reflects the extremely small quantities of flavorings added to base wines. However, the addition of flavorings significantly modified the sensory profiles of wines, with flavored wines, CH1+A, CH1+PF, CH2+PF, SH1+R and SH2+B in particular, exhibiting enhanced fruit and/or developed aromas and flavors, as a consequence of the use of flavor additives. In the case of Chardonnay wines, bottle aging tended to diminish the variation in sensory properties resulting from the addition of flavorings. However, the sensory impact arising from the addition of selected flavorings to Shiraz persisted after 12 months bottle aging. The potential for flavor additives to be used to mitigate wine sensory deficiencies has therefore been further demonstrated.

Supplementary Materials: The following are available online at www/mdpi.com/link, Table S1: Aroma descriptors and GC-MS method characteristics (retention times and ions) of key constituents of flavor additives. Table S2: pH, titratable acidity (TA), alcohol, residual sugar and volatile acidity (VA) of control and flavored Chardonnay and Shiraz wines, following bottling (t=0) and 12 months aging (t=1).

Acknowledgments: The authors gratefully acknowledge: the members of the Australian wine industry who provided wine; FlavorSense and The Product Makers for the provision of flavor additives; Laura Fassier for assistance with wine analysis; and the University of Adelaide staff and students involved in DA. This research was funded by Wine Australia and Y.S. held a Wine Australia scholarship (GWR Ph1102).

Author Contributions: Y.S., J.C., K.W. and S.B. conceived and designed the experiments; Y.S. and J.C. performed the experiments; all authors analyzed and interpreted the data; and Y.S., J.C. and K.W. wrote the paper, with T.J., R.R. and S.B. providing drafting and editing support.

Conflicts of Interest: The authors declare no competing financial interest.

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Table S1. Aroma descriptors and GC-MS method characteristics (retention times and ions) of key constituents of flavor additives.

Compound	Descriptors[a]	RT (min)	Ions[b] (*m/z*)
benzaldehyde	almond, burnt sugar	42.9	**106**, 105, 77
cinnamaldehyde	cinnamon	71.4	132, **131**, 103
β-citronellol	rose	57.1	81, **69**, 41
ethyl acetate	nail polish	6.6	70, 61, **43**
ethyl butanoate	fruity	12.3	88, **71**, 43
ethyl cinnamate	strawberry cream	75.4	176, **131**, 103
2-ethyl hexanol	floral, fruity	41.0	83, **57**, 41
furfural	earthy, wood	39.5	**96**, 95, 39
cis-3-hexenyl butyrate	green, fruity	39.3	82, 71, **67**
hexyl butanoate	apple peel	36.3	89, **71**, 43
α-ionone	sweet fruit	61.3	136, **121**, 93
β-ionone	violets	65.9	**177**, 135, 43
linalool	floral	44.6	121, 93, **71**
phenethyl acetate	floral, rose, fruity	59.7	**104**, 91, 43
phenethyl alcohol	floral, rose	64.6	122, 92, **91**
phenethyl isovalerate	fruity, pineapple	68.7	105, **104**, 57
α-terpineol	spicy	53.1	121, 93, **59**
vanillin	vanilla	94.3	152, **151**, 81

[a] Sourced from [26,32] and references therein. [b] Ions in bold were used for quantification.

Table S2. pH, titratable acidity (TA), alcohol, residual sugar and volatile acidity (VA) of control and flavored Chardonnay and Shiraz wines, following bottling (t=0) and 12 months aging (t=1).

Wine	Time	pH	TA (g/L)	Alcohol (% v/v)	Sugar (g/L)	VA (g/L)
CH1	t=0	3.5	6.2	12.9	4.6	0.5
	t=1	3.5	6.1	12.9	4.7	0.2
CH1+A	t=0	3.5	6.2	12.9	4.6	0.5
	t=1	3.5	6.2	12.9	4.6	0.2
CH1+PF	t=0	3.5	6.1	12.9	4.6	0.5
	t=1	3.5	6.2	12.9	4.6	0.2
CH2	t=0	3.4	6.6	12.0	2.6	0.2
	t=1	3.4	6.6	12.0	2.6	0.3
CH2+H	t=0	3.4	6.6	12.0	2.7	0.2
	t=1	3.4	6.6	12.0	2.7	0.3
CH2+PF	t=0	3.4	6.6	12.0	2.6	0.2
	t=1	3.4	6.6	12.0	2.6	0.3
SH1	t=0	3.6	6.2	13.8	0.5	0.5
	t=1	3.6	6.2	13.8	0.5	0.5
SH1+C	t=0	3.6	6.1	13.9	0.5	0.5
	t=1	3.6	6.1	13.9	0.5	0.5
SH1+R	t=0	3.6	6.1	13.8	0.5	0.5
	t=1	3.6	6.1	13.9	0.5	0.5
SH2	t=0	3.6	5.9	13.2	4.6	0.5
	t=1	3.6	5.9	13.2	4.6	0.5
SH2+B	t=0	3.6	5.9	13.2	4.5	0.5
	t=1	3.6	5.9	13.2	4.5	0.5
SH2+R	t=0	3.6	5.8	13.2	4.5	0.5
	t=1	3.6	5.8	13.3	4.5	0.5

Values are means of two replicates. TA measured as g/L of tartaric acid; residual sugar measured as g/L of glucose and fructose; VA measured as g/L of acetic acid.

Chapter 5. Conclusions and future work

Flavour additives are routinely used by food and beverage producers to enhance aroma and flavour intensity, and to mitigate bitterness and astringency (Longo & Sanromán 2006; Resurreccion 2007; Routray & Mishra 2011). These industries regularly seek consumer feedback to gain insight into product acceptability, and use flavourings to ensure products meet the sensory and quality expectations of their target market (Cardello 1994; MacFie 2007). In contrast, the wine industry invests resources into marketing strategies to promote existing wines (Lesschaeve, Norris & Lee 2002) rather than exploring the flavour and wine style preferences of their consumers.

The key aims of this study were: (1) to determine Australian wine consumers' acceptance of and attitudes toward the use of additives in wine and food production and to discover consumers' preferred flavours for white and red wines; (2) to explore the impact of natural flavour additives on the sensory perception and consumer liking of Chardonnay and Shiraz wines; and (3) to examine the impact of bottle ageing on the sensory and chemical composition of flavoured Chardonnay and Shiraz wines.

To address the first project aim, an online survey of 1031 Australian wine consumers was conducted to determine attitudes towards the use of additives including flavour additives during winemaking (Chapter 2).

Survey responses revealed that, irrespective of their self-reported level of wine knowledge, consumers rated their acceptance of natural flavours, natural colours and additives associated with health benefits (e.g. vitamins, minerals, and omega 3 fatty acids), significantly higher than commonly used, legally permitted additives in wines (i.e. oak chips, tannins, preservatives, acid). This was surprising, given that flavourings and vitamins are not commonly associated with wine, whereas oak chips, tannins and preservatives are familiar additives. Furthermore, highly knowledgeable consumers, who usually value traditional approaches to winemaking (Hughson et al. 2004), were as accepting of the use of natural flavourings as the less knowledgeable consumers. This was a particularly unexpected finding.

When asked about their acceptance of additives in food products, consumers rated natural flavour additives, vitamins, folate and omega 3 fatty acids favourably, but were less accepting of artificial flavourings and monosodium glutamate, i.e. their attitudes were similar to those for additives in wines.

These results suggested that consumers' acceptance of additives is not affected by the product, and justifies the wine industry investing in consumer based product development, as is commonly practised in the food and beverage industries to improve market performance (McEwan 1996; Costa & Jongen 2006).

The survey also determined Australian wine consumers' preferred flavours for white and red wines. Participants were asked to list their preferred wine flavours via an open-ended question, with 96% of participants answering this optional question. This provided an extensive list of flavours which could be used by the Australian wine industry to inform winemaking decisions that determine the style of finished wines. That said, it is important to acknowledge that flavour preferences may shift with time as market trends evolve.

Chapter 3 described the impact of natural flavour additives on the sensory profiles and consumer liking of flavoured wines. Flavour additions, based on the survey responses in Chapter 2, were made to four inexpensive commercial wines with an apparent impact on wine aroma and flavour, yet in a broad sense, the original wine style of base wines was retained. Results demonstrated the potential for flavour additives to improve wine quality; for example to enhance aroma and flavour intensity in years where grapes suffered due to poor seasonal conditions. Wines that lacked flavour intensity or displayed undesirable characteristics such as green aroma or bitterness could be modified through the addition of corrective flavourings. Furthermore, flavourings could be used to tailor wine styles to better meet consumers' expectations.

Finally, the application of flavour additives was found to be simple and time efficient, and allowed for additions to be made at different stages of production. In an example described in Chapter 3, the addition of an oak flavouring (as a mixture of several flavour additives) to an unoaked Chardonnay resulted in a flavoured wine which the panel perceived to be 'oaky'. Thus, if oak flavourings were permitted winemaking additives, winemakers could impart oak character to wine without the need for expensive, time intensive oak maturation regimes.

In another example, the addition of flavour additives (butter, orange, custard and raspberry) to a Shiraz base wine significantly diminished the intensity of undesirable green and earthy aromas and flavours. The wine industry typically uses copper fining to mitigate off-flavours such as cooked vegetables (DMS), rotten egg (H_2S), and cooked cabbage or sauerkraut notes (MeSH) (Franco-Luesma et al. 2016), but unfortunately copper contributes to the overall loss of varietal characters and dulls desirable attributes. In contrast, the use of flavour additives was found to provide specific mitigation of undesirable aromas while retaining or enhancing other targeted attributes. Future research might explore the potential of flavour additives to mitigate the various off flavours.

In some instances the addition of flavourings resulted in unforeseen outcomes. For example, the addition of flavourings (passion fruit, butter) to a Chardonnay base wine, was perceived by the panellists as significantly higher in bitterness, astringency and acidity. This was a surprising finding given that flavourings were added in minute amounts to the mixtures. Furthermore, basic analysis of the wines revealed that there were no variations in titratable acidity (as g/L of tartaric acid), pH and residual sugars (as g/L of glucose and fructose) in the flavoured wines compared with the control wines. It was therefore inferred that the increase in the perception of bitterness, astringency and acidity resulted from cross-modal interactions. In a cross-modal interaction, the addition of odourants, for example sweet smelling odours which do not possess a taste, to a mixture containing sucrose, may have the ability to enhance the perception of sweetness in the mixture (Stevenson, Boakes & Prescott 1998). Similarly, the addition of odourants (i.e. passion fruit and butter flavourings) to the Chardonnay base wine, resulted in an increase in the judges' perception of taste and mouthfeel characters although the compounds likely responsible for their sensations remained unchanged. This highlighted possible limitations of the use of flavourings, and reinforced the recommendation of Lesschaeve, Norris and Lee (2002), that flavour optimisation should be facilitated through the involvement of flavour producers and sensory professionals for each individual product. This finding also prompted chemical analysis of flavourings and flavoured wines, i.e. using gas chromatography-mass spectrometry, which was described in Chapter 4.

Research outlined in Chapter 3 also involved consumer tasting which aimed to evaluate the acceptability of flavoured wines compared to their corresponding controls. Participants (n=218) were recruited via methods including flyers posted in public places, social media (including Facebook and electronic newsletters) and from an internal wine consumer database. Participants who responded to the advertisement were more likely to represent consumers who were more involved with wine, and possibly more experienced in wine tasting than the average Australian wine consumer. The tasting revealed that collectively consumers did not significantly prefer flavoured wines over control wines, but segmentation of consumers based on their individual liking scores identified consumer clusters with distinct wine preferences. In this way, the wine industry could similarly identify segments of their target market who might be more accepting of flavoured wines.

Additional research could be undertaken with commercial wines of lower quality, and a broader range of flavour additives, to further validate the capacity for flavourings to be used to modify the sensory profile of wines. It would also be worth assembling an expert panel to evaluate the quality of the flavoured wines versus control wines.

The impact of bottle ageing on the sensory and chemical composition of flavoured Chardonnay and Shiraz wines was described in Chapter 4. In this study, control and flavoured wines were cellared under optimal conditions (at 15°C under Saran lined metal screw caps) for 12 months before compositional and sensory analysis. Descriptive analysis was undertaken to profile bottle aged wines, and a comparison was made between the data from wines post bottling (t=0) and after storage (t=1). A limitation of this study included changes, albeit small, to the DA panel membership between t=0 and at t=1. Ideally, the same panel members would have participated in both panels but this was not possible based on time constraints. Statistical analysis of the data attempted to address both changes in panel membership between DA panels at t=0 and at t=1, and a possible natural drift in performance within the panel at the two time points. This was achieved by considering: (1) panellist-time interactions; (2) product-time interactions; and (3) panellist-product-time interactions.

GC-MS analysis was undertaken to determine the composition of both flavourings and flavoured wines. The volatile profiles of flavour additives varied considerably; some flavourings comprised relatively few volatile compounds, whereas others comprised an array of constituents. Nonetheless, the most abundant volatiles in each flavouring were identified, although it is acknowledged that abundance does not necessarily imply organoleptic importance which requires consideration of detection thresholds and odour activity values.

GC-MS analysis of flavoured wines was inherently more challenging, since flavour additives were added at minute concentrations. As a consequence, it was difficult to quantify compositional changes directly attributable to flavourings. This highlighted implications for policing the addition of flavourings to wine, although analytical sensitivity could be improved with method development, for example through extraction of larger wine volumes. In the current study, however, the impact of flavour addition and bottle ageing was determined via DA. Comparison of sensory profiles of the wines at the two time points showed significant differences in the intensity of attributes. At t=0, DA panellists perceived that the intensity of Chardonnay base wines' attributes were significantly different than their counterpart flavoured wines, but after a year in storage (t=1) those differences were less perceptible, and the overall sensory profiles of the wines were found to be similar. Surprisingly, the comparison between the two time points revealed that the intensity of many white wine attributes (such as citrus, floral and stone fruit aromas) increased after 12 months. This is in contrast with previously published studies, which indicate that aged white wines typically display a decrease in the intensity of fruity and floral characters (Ramey & Ough 1980; Pérez-Coello et al. 2003).

The addition of flavourings to Shiraz base wines (t=0), resulted in two flavoured wines which were perceived to be significantly different to the base wines, and two flavoured wines that were relatively similar to the base wines. Post bottle ageing (t=1), DA panellists perceived those two quite distinct flavoured wines to still stand out relative to the non-flavoured counterparts, whilst the other two flavoured wines remained quite similar to the base wines. In general, the sensory comparison between the two time points revealed an overall decrease in the intensity of most attributes after a year of bottle ageing. The impact of bottle ageing on red flavoured wines did not reveal any unusual increase or decrease in intensity of attributes, or the formation of off flavours post ageing, that may suggest either decomposition of flavourings or interaction between flavour additives and wine constituents that may significantly impact the sensory profile.

The Australian wine industry faces challenges associated with climate change and occasional poor seasonal conditions, increases in the cost of production and shipping, a rise in global competition, and the need to remain at the forefront of new trends and style preferences of wine consumers. The results from this research demonstrated the importance of combining consumer research, sensory analysis and compositional analysis to gain a broader understanding of consumer acceptability of flavourings, quality expectations and liking drivers. Flavourings were found to offer the potential to overcome sensory deficiencies associated with difficult environmental conditions and/or tailor wine styles to better meet consumer needs and expectations, although not all producers and consumers will accept the use of flavour additives in wines. In Australia, the addition of flavourings to compliment, enhance or modify existing wine aroma contravenes the legal definition of wine. Flavourings would therefore need to be added to the list of legally permitted additives in Australia (Food Standard Australia New Zealand 2011), and in other wine producing countries to which Australia exports wines. It is not likely that flavourings will represent a legally allowable additive in the near future.

Future work arising from this study:

- Determine consumers' acceptance of and attitudes towards the use of flavourings in wines in other wine producing countries.
- Investigate the impact of timing of of flavour additions on the sensory properties of the flavoured wines.
- Explore the impact of flavourings on wine quality using a panel of expert judges.

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