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CHAPTER 1

INTRODUCTION

This research began as a component of a multidiscipline wine programme, "Quality New Zealand Wines," funded by the Foundation of Research, Science and Technology (UOAX0404) and the New Zealand wine industry. This programme aimed to understand the flavour components that create styles of Sauvignon blanc for international markets. Individual research teams within the programme investigated regional flavour characteristics, distinctive chemical compounds, the effects of viticulture practices, and the use of novel yeasts in wine production. The contribution of this thesis, as a component of the research, was to define the flavours perceived by a sensory panel that was trained to conduct the research of this thesis. This sensory panel evaluated Sauvignon blanc wines produced by the associated research teams, as well as other wines produced commercially and purchased for inclusion in this research.

This thesis is comprised of three sections, and the thread between these sections is that a trained sensory panel was employed in each portion of this PhD research.

1.1 Sensory Evaluation

Sensory evaluation came about as a way for the food industry to reduce risk by enlisting a panel instead of a single expert to evaluate products, such as coffee or tea. Prior to the existence of trained panels, a single expert would evaluate the product (i.e. coffee) for acceptance or rejection. This reliance on a single expert was risky for the company because if the expert left or died, all of his or her expertise was no longer available. There was also the risk of the expert ageing and losing his or her sensory abilities. It was also not appropriate to rely solely on one person's sensory perception of a product. A group of individuals' assessments could mitigate a single individual's insensitivity to a specific product characteristic (Lawless and Heymann, 1999). This group assessment approach has since evolved into descriptive analysis. Descriptive analysis entails the use of a group of individuals, who are trained to recognise, describe and define product characteristics using reference standards as a tool. This process will be described and detailed below.

Sensory science is a discipline that uses some or all of the five senses (taste, smell, sight, hearing, touch) to evaluate a product. Instruments that measure the chemical characteristics of products have been developed to help understand and try to predict sensory perception. For example, refractometers can be used to measure the sucrose concentration of an aqueous solution. These measurements can then be correlated to panellists' perception of the solution's sweetness (Murphy and Cain, 1980). The perception of sweetness can change when the sucrose solution is altered by addition of other chemical compounds. As an example, if one evaluates a simple sucrose solution (2%), it tastes very sweet. Similarly, a 0.2% citric acid solution tastes sour. However, when these two compounds are combined (2% sucrose and 0.2% citric acid) in water, both the sweetness perception and sourness perception are reduced (Harker et al. 2001).

Attempts to find an instrument that duplicates the brain's interpretation of sensory information have failed so far, at least in part because the brain and its receptors are very complex. To better understand how the brain interprets sensory information, sensory scientists use humans as their measuring tool. In order to perform this task effectively, a human (instrument) needs to be calibrated. This calibration is often achieved via a training process of introducing reference standards and having the panellists become familiar with the quantitative assessment of these standards through a process called descriptive analysis (Stone and Sidel, 2004). The panellists are required to remember specific tastants, odours, colours, sounds and textures, using the reference standards associated with a specific product.

Two of the main approaches for training panels are the Sensory Spectrum method and Generic Descriptive Analysis (developed by Stone and Sidel (2004) under its proprietary name, Quantitative Descriptive Analysis).

The Sensory Spectrum method trains the panellists using pre-established generic reference standards, which are fixed for all samples. A key limitation in using the Sensory Spectrum approach is that the sensory attributes of the references standards may not always be well calibrated to the sensory attributes of the target product. For example, the reference standard provided for the assessment of tropical attributes might be formulated from a combination of pineapple, coconut and mango fruit characteristics. This formulation may or may not be an appropriate reference standard for an accurate assessment of the tropical attributes found with a specific varietal wine, since a tropical note in a Sauvignon blanc wine may be quite different than tropical attribute in a Chardonnay wine. This gap between the

attributes of the reference standard and the attributes of the target product may confuse the panellists and impair their progress in developing their ability to confidently identify and associate specific sensory phenomena with descriptive terms. Another liability of the Sensory Spectrum method is that the required component reference standards may not be globally available. A further disadvantage of the Sensory Spectrum method is that it requires much more time to be able to adequately train the panellists. For example, it took my panel over 70 hours of training to master this method in order to execute the sensory assessments of Chapter 3. These combined limitations were influential in my decision to use the Generic Descriptive Analysis for my research.

The Generic Descriptive Analysis process begins with the panel leader guiding the sensory panel to discover the attributes of the target product, and the subsequent development of a set of descriptive terms (lexicon). In this approach, the panel leader has a more facilitative role rather than a directive role, as required when using the Sensory Spectrum method (Lawless and Heymann, 1999). The panellists develop these terms by evaluating different variations of the product. The panel leader does not create these terms, but facilitates and provides physical samples to represent the attribute terms. These terms are defined by the consensus of the panel, and each of these attributes has a reference standard that defines each descriptive term. An example of this might be a 1% sugar solution being associated with a term of 'sweetness'. The panellists assign a numerical value for the reference standard (e.g. 1% sucrose = 100). The assessment involves the product's attributes (e.g. sweetness) being measured in relationship to the reference standard, to generate an overall profile of the product.

In most circumstances only one reference standard is used for anchoring an attribute. If panellists are having difficulty in consistently rating an attribute, the panel leader may add different concentrations of the reference standard, to provide the panellists with a reference anchor at the top of the scale and at the bottom of the scale. In most cases, reference standards are presented to the panel at an intensity that is approximately two-thirds of the full concentration scale of the attribute.

After the panellists attain a full familiarity with the aroma defined by the reference standard and can recall the associated descriptive terms, they begin to evaluate product based on these attributes. By statistically comparing panellists' scores for each reference standard a panel leader can determine when a panel is ready for product assessment. The panellists measure the intensity of each of the product's

attributes in relationship to the corresponding reference standards, and their scores need to be consistent and statistically within range of the other panellists. After the terms and standards are defined and mastered, the panellists begin trial evaluations on different examples of the product. These evaluations are performed individually by each panellist, and the evaluation data from each panellist are compiled to construct the product's attribute profile (Stone and Sidel, 2004).

1.1.1 Trained sensory panel

A trained sensory panel is normally comprised of 10 to 12 individuals. Descriptive analysis is a sensory technique that involves training individuals or panellists in the unbiased evaluation of products. There is a panel leader who serves as a facilitator of the panel and does not participate in evaluations (Stone and Sidel, 2004). The panellists are normally screened for their sensory acuity through tests such as threshold determination (ASTM, 1991) and odour identification. The two common tests for odour identification both have disadvantages. One test involves putting flavours in an aqueous solution and asking panellists to describe and identify the odour. Interpretation of this test can be quite subjective in determining whether the panellist has accurately identified the odorant. For example, asking potential panellists to generate descriptive terms for kiwifruit odour can result in terms as "fruity", "grassy", "artificial candy", "slight vomit", which might be very precise, but not include the most accurate term. An alternative, simpler approach uses a booklet of 25 odorants called an UPSIT (University of Pennsylvania Smelling Identification Test). The panellists are instructed to scratch a patch in the book, which releases an odorant, and the panellists are asked to identify the odorant from a set of four possible choices. The method is simple to administer and assess, but has the disadvantage that it does not assess an individual's ability to independently articulate and describe odours. Additionally, there are odorants such as root beer and dill pickle, which may not be commonly familiar among all cultures.

Once a panel has been selected, one descriptive analysis methodology begins training with establishing the reference standards. The panellists determine the reference standards through the guidance of the panel leader. Natural products and/or chemical flavour compounds are used as reference standards, and the number of attributes included needs to encompass the full range of the product's characteristics (Noble et al., 1987). If there are too few attributes evaluated, panellists may inadvertently merge ratings of the missing attribute into the rating for existing attributes. This phenomenon is referred to as "dumping." Schifferstein

(1996) compared panellists' intensity scores for a fruit flavour mixture. He found that when panellists were asked to assess the mixture with a ballot that did not include attributes for "green odours", and the assessed mixture was altered with an additional chemical compound that exhibited "green odours", panellists would compensate by increasing their intensity ratings for some of the fruit attributes. This illustrates the importance of controlling the available number of descriptors appearing on the assessment, to ensure that all of the characteristic attribute categories have been provided to the panellists for their consideration. Sometimes including an "other" category can alleviate the "dumping" effect observed by Lawless and Heymann (1999). However, when there are too many attributes to rate, panellists may repeatedly rate the same intensity for several related attributes. For example, a panellist may rate a wine with three separate intensity scores of 50 for each of the attributes of coconut, pineapple and mango, even though the aroma being detected may be more precisely defined by one attribute, such as "tropical." Another liability of including too many attributes is that this quantity may limit the number of samples the panel can effectively evaluate, given the amount of time available for assessments. Some researchers have reported panellists recording lower intensity scores when there were a high number of attributes to rate, as compared to when there were fewer attributes provided for the same assessment (Frank et al. 1993). These findings would benefit from further study, to determine if additional panellist training could minimize these effects.

The panel leader must also prevent panellists from using hedonic terms to describe products. Hedonic terms such as, "delicious," "bad" or "high liking" are not terms used in descriptive analysis. Proper descriptive analysis terms should describe an attribute, be definable, and have quantifiable levels of intensity (Meilgaard et al., 2007).

1.1.2 Controlling bias

External factors such as noise in the booths, external odours, and lighting are standardised and controlled. These physical factors are managed so as to reduce the bias in the data collection process, allowing panellists to concentrate on performing their assessments properly, free from external distractions. The reduction of extraneous audio and visual distractions allows panellists to focus on the product being evaluated, and improves the accuracy of the data obtained from their assessment (Lawless and Heymann,1999; Meilgaard et al., 2007). Sample size, sample container and sample temperature are also factors that need to be controlled

to reduce bias (Lawless and Heymann, 1999). For example, if one wine is assessed at 4°C and the following wine is assessed at 20°C, there will be detectable differences in the headspace concentrations of volatile compounds, thereby eliciting different aroma profiles from the two wines. This temperature effect was substantiated in a recent study by Ross and Weller (2008) assessing the intensity of white wine and red wine aromas. Their results showed that at 4°C, 10°C and 18°C, the aroma intensity of white wine was significantly increased with every increase in serving temperature. However, for red wine served at temperatures of 14°C and 18°C, there were no significant differences in aroma intensity detected; only at temperatures of 23°C were any significant increases noted in the aroma intensity of the red wine samples.

1.1.2.1 Panellist physiological bias

Panellists' physiological factors need to be considered when controlling bias. Of the physiological factors such as allergies, dentures, or age, the latter is probably the most important to wine research. Panellists over 60 years old are not normally recruited because as humans age, their sensory organs degrade. People aged 40 to 55 years begin to notice changes in their vision, as reading without glasses becomes difficult. The olfactory system also deteriorates quite rapidly in humans over 60 years of age. The University of Pennsylvania has conducted many studies into age and anosmia (inability to smell). By the age of 60, the degree of anosmia increases at such a rapid rate that when an individual reaches age 80, it is very probable that they are going to be anosmic (Tourbier and Doty, 2007). Most sensory panellists are recruited between the ages of 18 and 60. It appears that while olfactory losses are apparent in aging adults, losses in taste sensitivity are less profound (Murphy, 2008), and this incongruence can affect how the elderly perceive products in comparison with their younger counterparts.

There are also some differences in odour perception found between males and females. Females have been measured to have higher perceived odour intensities, and lower detection thresholds, as well as increased abilities in odour discrimination (Seubert et al., 2008). It has been postulated that this could be an evolutionary factor related to women being in charge of offspring and needing to perceive danger, such as fire, so she can rapidly react to move herself and her offspring.

Physiological factors can normally be identified through a screening questionnaire. For example, if a person has stated in the screening questionnaire that he or she is

allergic to sulfites, this individual would not be suitable for a wine panel because most wines contain sulfite compounds. Screening questionnaires typically ask questions about age, gender, food sensitivities, allergies and long term health ailments.

Ailments such as a cold can impair panellists from perceiving odorants because under the influence of a cold virus, the olfactory bulb is covered with a mucous film that reduces the ability of the receptors to be stimulated by odorants. Panellists are asked to stay at home if they become ill before a training or assessment session.

1.1.2.2 Panellist psychological bias

In addition to controlling physical factors, sensory scientists also consider which psychological factors are controllable. As human beings, panellists are affected by certain psychological influences, including Logical Error, Stimulus Error, Contrast Error and Mutual Suggestion Error (Meilgaard et al., 2007).

Logical Error occurs when a panellist has prior knowledge of a parameter of a product they are testing, or knows the objective of the test, such as if they can perceive any differences between the sub-regions of a wine's geographical origination. This information might bias a panellist to rate certain attributes higher or lower, based on their previous knowledge of what the flavours of each sub-region should be. The key to preventing this error is to withhold all information, about the products being assessed or the objectives of the tests, prior to any assessments scheduled for the panellists. This biasing psychological effect can also be reduced by performing product assessments in a double blind setting, where the panel leader is also unaware of any sample identities, and therefore is less likely to influence the performance of the panellists.

Stimulus Error is similar to Logical Error in the respect that if panellists are given information during the test, this information may influence their assessment. If panellists were able to see a golden brown colour (stimulus from product) in a white wine they may assume this wine was older and assign lower ratings to fruity flavours lower, or higher ratings to oxidised flavours. In this example, the Stimulus Error can be eliminated by using green lighting in the booths to effectively mask any colour perceptions of the wine. Other ways of eradicating Stimulus Error is by limiting influences from the product such as, controlling sample amount, sample container and sample temperature.

Contrast Error occurs when a sample that is very intense is followed by a sample that is low in intensity. The tendency is for a panellist to rate the latter sample lower than it actually is, due to the fatiguing influences of the first sample's intensity. Contrast Error can be alleviated by cleansing the palate between samples, or by presenting assessment samples in a randomised order. Panellist training can also alleviate this error if panellists are trained to 'zero' their palate between samples, either by smelling a neutral sample, taking a rest between samples, or through some similar diversionary activity that diminishes the dominating effects of an intense sample. Randomising the samples will reduce Contrast Error through reducing the number of contrasting samples being served next to each other.

Lastly, Mutual Suggestion Error occurs when people discuss the samples they are evaluating. If one panellist mentions strawberries, another panellist might begin to think that they also perceive strawberry aromas in the product. Mutual Suggestion Error is alleviated by placing panellists in separate booths, and discouraging any discussions during the product assessment session.

One other psychological factor that has been taught as having an effect on panellists' performance is motivation. Intuitively, sensory scientists believe that when panellists are motivated they perform well; however, when they are not motivated they become bored and their performance declines (Meilgaard et al., 2007). As a result, panel leaders use recognition and rewards to ensure that panellists remain motivated (Word and Gress, 1981).

1.2 Wine Sensory Evaluation

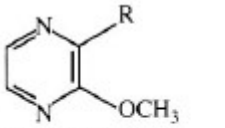
As stated earlier (Section 1.1), before the 1940's many quality assessments of wine were performed by single individuals. With increasing consumer demand and more discerning consumer palates, large wine companies realized the importance of using objective measures, supported by statistical analysis, to review the quality of their wines and the wines of their competitors. In the 1960's, three wine researchers at the University of California in Davis, Maynard Amerine, Rose Pangborn, and Ed Roessler, decided to apply a more scientific approach to the sensory assessment of wine quality. (Amerine et al., 1965). Amerine was professor in oenology, Pangborn was a professor in sensory science, and Roessler was a professor in mathematics. They attempted to debunk the myth that only wine aficionados had the capabilities to consistently evaluate wine. They did not deny the important role of experience and familiarity, but they postulated that most humans possessed the ability to discriminate

and discern the different flavours associated with wine (Amerine and Roessler, 1976). They believed that the development of refined sensory skills, combined with the use of statistical analysis for evaluating the significant measured differences evaluated wines, would lead to consistent results for both the consumer and the wine professional. Wine researchers have since embraced sensory evaluation as a scientific way of measuring human perception of flavour.

1.2.1 Sauvignon blanc wine

Sauvignon blanc wines originated in France, where the grape varietal is grown in the upper Loire valley (Sancerre or Pouilly Fume) and Bordeaux (Graves) (Johnson, 1974). The grape ripens with moderate to high levels of acidity and sugar content, with a pungent aroma and flavour (Cooper, 2002). Sauvignon blanc wines are known for their distinctive aroma and flavour characteristics (Clarke and Rand, 2001). This particular white wine varietal has been chemically analysed by many researchers and found to contain several important aroma components.

Augusten et al. (1982) initially found methoxypyrazines as the principle contributor to the green characters present in Sauvignon blanc wine. The three main methoxypyrazines in wine are illustrated in Figure 1.1



R: $CH_2CH(CH_3)_2$ 2-Methoxy-3-isobutylpyrazine
R: $CH(CH_3)_2$ 2-Methoxy-3-isopropylpyrazine
R: $CH(CH_3)CH_2CH_3$ 2-Methoxy-3-*sec*-butylpyrazine

Figure 1.1 Three methoxypyrazines of wines: 2-methoxy-3-isobutylpyrazine (MIBP), 2-methoxy-3-isopropylpyrazine (MIPP) and 2-methoxy-3-sec-butylpyrazine (MSBP) (Ribereau-Gayon et al., 2000)

A team of researchers in Australia conducted the initial quantitative analyses of methoxypyrazines in wine. They associated the characteristic capsicum, herbaceous, green notes in Sauvignon blanc to 2-isobutyl-3-methoxypyrazine (MIBP) (Harris et al., 1987; Allen et al., 1991; Lacey et al., 1991; Allen and Lacey, 1999). Murat (2001) attributed MIBP as the most important of the three methoxypyrazines

because MIBP showed the highest concentration in the South African Sauvignon blanc wines he evaluated. Lacey et al. (1991) found that New Zealand Sauvignon blanc wines had significantly higher levels of MIBP in comparison to Australian Sauvignon blanc wines. Further studies showed that subjects could detect a difference in neutral wine when as little as 1 to 2 ng/L of MIBP was added. The researchers also recorded that green vegetative notes were perceived when 8 ng/L of MIBP was added to neutral wine (Allen et al., 1991).

The methoxypyrazines are present in the grapes and their concentration decreases as the grapes ripen (Allen and Lacey, 1999). Marias et al. (1998) found that MIBP exhibited a low detection threshold in Sauvignon blanc, even as it was measured at relatively low concentrations in the wine. These two facts led him to hypothesize that MIBP was a high impact compound, in the aroma of Sauvignon blanc wines.

It was in the early 1990's that a French research team isolated thiol aroma compounds (Darriet et al., 1995). These thiol compounds were later described to contribute flavour characteristics such as boxwood, tropical, sweat, grapefruit, cat urine, broom, eucalyptus, black currant bud, passionfruit and gooseberry (Dubourdieu et al., 2006). Unlike the methoxypyrazines that occur naturally in the grapes, thiols are chemically produced during the grape fermentation process.

The flavour characteristics elucidated by Dubourdieu have been ascribed to the thiol by-products of yeast fermentation (Tominaga et al. 2000, 1998b). The yeast acts upon the odourless thiol precursors in the grapes to produce aromatic thiol compounds in the wine (Charters, 2004; Dubourdieu et al., 2006). The term *thiol* refers to the S-H group on the molecule (Figure 1.2). In the fermentation of the Sauvignon blanc grape, the cysteine – S-conjugate precursor is cleaved during the glutathione metabolic pathway, and the by-products are the aromatic thiols (Tominaga et al., 1998b). These aromatic thiols in the wine are 4-mercapto-4-methylpentan-2-one (4MMP), 4-mercapto-4-methylpentan-2-ol (4MMPOH), 3-mercapto-3-methylbutan-1-ol (3MMB), 3-mercaptohexan-1-ol (3MH) and 3-mercaptohexyl acetate (3MHA) (Ribereau-Gayon et al., 2000). The latter two compounds will be the focus of this thesis. These aromatic thiols occur in other wines, such as Gewürztraminer, Scheurebe, and Muscat (Guth, 1997; Tominaga et al 1998b).

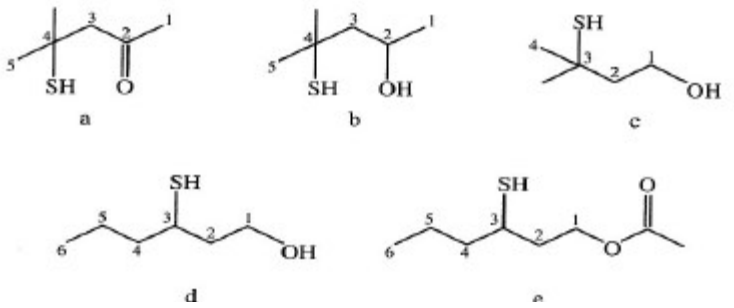


Figure 1.2 Volatile thiols in Sauvignon blanc wine; (a) 4-mercapto-4-methylpentan-2-one (4MMP), (b) 4-mercapto-4-methylpentan-2-ol (4MMPOH), (c) 3-mercapto-3-methylbutan-1-ol (3MMB), (d) 3-mercaptohexan-1-ol (3MH), (e) 3-mercaptohexyl acetate (3MHA) (Ribereau-Gayon et al., 2000)

Table 1.1 Detection thresholds of thiols and methoxypyrazines in water found in the literature (ng/L)

Compounds	**Detection thresholds in water found in the literature (ng/L)**	
4MMP	20	Tominaga et al., 1998b
4MMP	0.1	Tominaga et al., 2000
3MHA	2.3	Tominaga et al., 2000
3MH	17	Tominaga et al., 2000
MIBP	2	Buttery et al., 1969

Tominaga et al. (1998b) concluded that because these thiols were present in levels much higher than their perception threshold (Table 1.1), they must be contributing to the varietal style of Sauvignon blanc wine. Swiegers et al. (2007) found that using genetically engineered yeasts that produced high levels of thiols during the fermentation process subsequently yielded wines that scored high in aroma characteristics attributed to these thiols when these wines were assessed by sensory panels.

1.2.2 New Zealand Sauvignon blanc wine

New Zealand wine growing regions span the latitudes of 36°S to 45°S. In the Northern Hemisphere these latitudes would be equivalent to the latitudes extending from the Bordeaux region of France to southern Spain. Due to the maritime influences of the surrounding Tasman Sea and Pacific Ocean, the climate of New Zealand is very different from its northern hemisphere antipode. New Zealand's climate is temperate, and the air is generally humid, especially in the north island, with frequent breezes passing over the island. These weather phenomena are generated by the interaction of hot air masses from Australia, frigid airs from Antarctica, and the expanse of ocean surrounding New Zealand. The weather brings cooler summers and warmer winters in comparison to its antipode in the northern hemisphere (Cooper, 2002).

Figure 1.3 The eleven wine growing regions of New Zealand.
(http://www.tourism.net.nz/images/new-zealand/attractions/wineries/wine-map.jpg)

There are eleven wine growing regions within New Zealand (Figure 1.3). In 2006, there were 530 wineries, producing a vintage of 133.2 million litres of wine. The average New Zealander only consumes 12.1 L/year, so export sales are critical to achieve the projected growth of $1 billion by 2010. The United Kingdom, the United States, and Australia are New Zealand's top three wine export markets. Marlborough is the largest wine region within New Zealand, with 50.8% of vineyard hectares planted in 2006. Sauvignon blanc is the most planted grape variety in New Zealand. In 2006, Sauvignon blanc comprised 39% of all new grape plantings. (http://www.nzwine.com).

Though Sauvignon blanc has been cultivated in France for centuries, this grape varietal wasn't introduced into New Zealand until the first plantings in Marlborough in the mid 1970's (Clarke and Rand, 2001). New Zealand Sauvignon blanc wines were not commercially available until the early 1980's. A turning point for the wine's success occurred in 1986, when Hunter Sauvignon blanc won the top wine award at a wine show in London. Exports jumped 250% over the following two years as the international wine community began to take note of New Zealand Sauvignon blanc as a unique wine (http://www.nzwine.com). Wine critics and wine writers began to experience and write about New Zealand Sauvignon blanc. New Zealand Sauvignon blanc, and even more specifically, Marlborough Sauvignon blanc, was described as having an intense and distinctive flavour profile. A USA wine critic, Paul Gregutt, wrote in the Seattle Times (Gregutt, 2007.)

> The Marlborough style, which is undeniably the varietal benchmark, is described as "pungently aromatic and explosively flavored, its zesty character redolent of green bell pepper and gooseberry with tropical fruit overtones."

Prior to the research of this thesis there were no extensive scientific investigations as to whether the combination of chemical, sensory, and consumer data of Sauvignon blanc wines from the Marlborough region of New Zealand fostered a distinctively unique style. Wine critics and writers had described New Zealand Sauvignon blanc as being different, but at the onset of this research the scientific literature had not yet substantiated this alleged reputation.

1.2.3 Trained panel and descriptive analysis

In 2004, before the start of this thesis, I screened a group of 27 individuals experienced in the use of descriptive analysis for their olfactory and gustatory acuity,

their capacity for flavour memory, and their ability with descriptive language. The screening tests involved cognitive remembrance testing, wherein a panellist needed to smell and taste a Sauvignon blanc wine at the beginning of the screening and again at the end of the screening session. The panellist was then asked to select the wine from a line-up of five wines, which included a second Sauvignon blanc. The UPSIT booklet was used for the olfactory screening test (Section 1.1.1). For screening panellist's retronasal and descriptive abilities, they were asked to describe and identify gels spiked with different flavours. Panellists were also tested for their gustatory ability by being asked to rank aqueous samples containing different sucrose concentrations. From this pool of 27 candidates a group of 14 people were selected to comprise the New Zealand Sauvignon blanc wine panel.

The first task the panel accomplished was the development of a lexicon of terms to describe the sensory attributes of Sauvignon blanc wine. Thirty-three attributes were identified. A New Zealand Sauvignon blanc wine wheel was created from the descriptors generated by the panellists, with additional input from local winemakers (Appendix A). Noble et al. (1987) had created the first wine wheel to facilitate communication of flavour attributes. The New Zealand Sauvignon blanc wine wheel adopted a similar format as the Noble et al. wine wheel.

After the Sauvignon blanc lexicon was developed, key attributes were selected and defined. The key attributes were designated by the frequency of their use by a majority of panellists for describing the wines. The panel leader determined the concentration of standard chemical compounds that were selected to serve as representative reference standards for each attribute. The panellists were given a 150mm linear scale in which to rate the intensity of each reference standard. Panellists established consensus intensity values for each reference standard, based on their perceptions of the intensity of that attribute in the wine. The reference standard could have a value anywhere from 0 to 150; however, most values were rated at values of 80 to 120.

The first part of the panel training consisted of understanding and identifying the attributes through repeated exposure to reference standards. Reference standards were presented in standard ISO wine glasses with a watch glass lid, and labelled with a random three digit code. After assessments were completed, panellists met in a round table discussion to receive and discuss results. If panellists could not

correctly identify a reference, they were asked to assess the sample again before moving onto the next step of the training program.

The second part of training consisted of the assessment of different Sauvignon blanc wines, with the selection of chosen wines intended to represent a variety of intensities for each of the attributes. The wines were rated on a 150-mm unstructured linescale. The wines were served in the same manner as described above. The trained panellists rated the intensity of each attribute from 'Absent' to 'Extreme' on an unstructured linescale (Appendix B). The goal of the second part of the training was to get the panellists to arrive at results which were within a narrow range from each other. Some panellists are more sensitive than other panellists to certain attributes. This is why more than one panellist is used in assessments, to account for anomalies.

All the identifying reference standards and assessments were performed in booths with green lighting at the HortResearch Sensory and Consumer Science Facility in Mt. Albert, Auckland, New Zealand. The green lighting used in this experiment had been developed and used successfully for masking the colour of Gold kiwifruit that had been intentionally picked green in order to determine how early Gold kiwifruit could be harvested whilst still achieving an adequate development of flavour. The green lighting masked white wine colour and helped minimize the influence of colour on panellist's wine assessments.

A positive airflow was maintained to reduce any odours not associated with the wine. Wine was served at 20°C in standard ISO wine glasses (Gilmours, NZ) with watch glass lids. Double filtered water and plain water crackers were used as palate cleansers (Lawless and Heymann 1999). These precautions were taken to minimise bias as described in Section 1.1.2.

The panellists rated intensities of the selected attributes for each wine on computers operating on Compusense^{TM} Version 5.0 Guelph, Canada. A comments section was made available for the occasion when panellists did not find attributes on the list that adequately described the wine they were assessing. The panellists would name the attribute and rate its intensity. If the comments section was used by the majority of the panellists then the panel would meet to discuss and define the new attribute, its reference standard, and its intensity value. Descriptive Analysis was the method described in this section (Lawless and Heymann, 1999).

1.3 Olfactory System

Our sense of smell determines anywhere from 75% to 95% of our perception of flavour (Noble, 1996). Humans may have only five taste receptors: salt, sour, sweet bitter and umami (Lawless and Heymann, 1999), but the sense of smell compensates with nearly 350 functional odour receptors, allowing us to describe over 400,000 aroma compounds (Stockhorst and Pietrowsky, 2004). This may explain why odour is an important component in the description of flavour.

From an evolutionary standpoint, our senses have been important in keeping humans from danger. In prehistoric times, seeing or hearing a predator helped humans survive, but the sense of smell was also critical, as it was this sense that enabled humans to detect spoiled foods or the approach of an uncontrolled fire. The sense of smell still protects humans from getting sick or even dying (Stockhorst and Pietrowsky, 2004). Pregnant women have been found to be more sensitive to smells, perhaps to protect their unborn children from possible environmental threats (Nordin et al., 2005).

Scientists are continuing to discover the mechanisms that create and regulate our sense of smell. Linda Buck and Richard Axel recently received a Nobel Prize for mapping the genetic structure of the human olfactory system. They discovered that there are about 1,000 chemoreceptor genes involved, which represent nearly 3% of the total human genome (Buck and Axel, 1991). Humans have 1000 chemoreceptor genes but only 350 are functional odorant receptor genes – unlike a mouse, which has 1200 chemoreceptor genes, and 900 of those are functional odorant receptor genes (Bargmann, 2006).

Odour perception involves the biochemical process of odour molecules stimulating the G-protein-coupled receptors on the olfactory neurons. The complete odour molecule is matched with potential odour receptors, which are located on the olfactory bulb. The bulb has nodules that are called glomeruli. The axons of the olfactory neurons extend towards the glomeruli. When these olfactory neurons are stimulated, the sensory information is relayed across a second set of neurons where the data is recoded for identification by the brain (Shepard, 2006).

There are two ways that the odour molecules come in contact with the olfactory bulb, which is located behind the bridge of the nose. Odours can either be sniffed through the nose, which is referred to as orthonasal, or odour molecules can arrive at the

back of the nose via the throat, which is called retronasal. While humans sip wine, the closing of the throat that occurs when swallowing creates a vacuum at the back of the nose. This vacuum releases odour molecules from the wine being swallowed, and carries the molecules away from the back of the nose and throat, and up to the olfactory bulb. Inhaling air through the mouth prior to and/or after swallowing will also carry odour-laden molecules in this retronasal fashion (Lawless and Heymann, 1999).

Wine judges can be observed making slurping and sloshing noises within their mouths while assessing a wine. Since the intake of the wine's alcohol would quickly impair their judgement, wine judges do not swallow the wine. Without swallowing the wine, wine judges are apt to miss any of the taste components that would be released in retronasal passage, so they must compensate by using various mouth agitation techniques to release the volatile flavour components of the wine (Goode, 2006).

When we look at the evolution of our senses, the physical stimuli involved with the sense of sight (the colour spectrum, the physical properties of light, etc.) have been relatively stable and constant, whereas the stimuli involved with the sense of smell have changed over time. Odours which come from model airplane glue or automobile exhaust were not present even a century and a half ago. The olfactory system must constantly adjust to different cues, whether they are environmental or evolutionary in nature. The odour information is taken into the brain for higher order mapping, where the perception can be either innate or a learned behaviour (Bragmann, 2006). For example, odours are processed in the frontal and temporal lobes of the brain, but also in the hypothalamus (memory), where memory links language to odours (Buchanan et al., 2003). Smell and memory also have a close association within the brain. Recent studies have found that when subjects are exposed to a distinctive odour while they are learning new material, their subsequent recall of the learned material is improved when they are allowed to smell the distinctive odour again (Jacob, 2002). Lorig (1999) postulated that functions of language processing and odour recognition share the same neural substrate, sometimes making it difficult for people to articulate odours. Shepard (2006) felt that odour imaging is how we remember flavours, in a process similar to how one usually remembers the image of a person's face before recalling the associated name. Likewise, a person can learn to remember the names of people or sensory perceptions by associating the stimulus image with specific language cues.

Wine connoisseurs or professional tasters are people who have the capability of remembering descriptive words they have associated with the perception of specific aromas. A study in Italy used FMRI (functional magnetic resonance imaging) in an attempt to understand how this process occurs (Castrioto-Scanderberg et al., 2005). These researchers compared the brain activity in both experienced and novice tasters as they evaluated wines. It appeared that both groups had the insula and orbitofrontal cortex activated during the tasting part of the exercise, but after this activation the expert tasters also had their amygdala-hippocampus area activated. In the aftertaste portion of the exercise the novices had their amygdala-hippocampus area activated but only on the right side, whereas the expert tasters experienced activation on both sides of their amygdala-hippocampus area.

Grabenhorst et al. (2007) reported that the orbitofrontal cortex is where we assimilate the information from taste and smell receptors with reward (like/dislike) values. The experts differed from the novices in that during the tasting sessions their amygdala-hippocampus was activated. The amygdala is associated with motivation and the hippocampus is associated with memory functions. With this stimulation observed, the Italian researchers concluded that the experts were consequently more motivated to associate descriptive terms with their olfactory perceptions of the wine. The other part of the brain which was stimulated in the experts was the left dorsolateral prefrontal cortex, which is linked to the thinking strategies. The wine experts were analysing and interpreting the aroma, using language associated with the wine (Goode, 2006).

Stockhorst and Pietrowsky (2004) reported that humans discriminated unfamiliar odours poorly, but with increased exposure their acumen improved. Trained panels may also be exposed to unfamiliar odours, but become more familiar with these odours through the repetitive exposures that comprise the process of panellist training. These repeated exposures improve panellist's language recall performance, and their recall proficiency can be assessed by measuring the consistency of their assessments between replicates.

1.4 Perception Interactions

1.4.1 Thresholds

Thresholds are sensory levels at which an individual perceives a stimulus. An example of stimulus can be “sweetness” (sucrose) for taste, or “cherry” (benzylaldehyde) for odour. For the purpose of this thesis there are four types of thresholds.

Detection threshold is the lowest concentration of a stimulus capable of producing a sensation that can be perceived by human sensory receptors. Recognition threshold is the level at which a specific stimulus can be recognised and identified (e.g. ‘sweet taste’ for sucrose). The concentration of the threshold stimulus is always higher for recognition threshold than for detection threshold.

Difference threshold is the range of change in the stimulus concentration necessary to produce a notable difference between two stimuli. Lastly, there is the terminal threshold, which is the magnitude of a stimulus above which there is no increase in perceived intensity (Lawless and Heymann, 1999). These four thresholds apply to both odour and taste stimuli. However, stimuli concentrations for odour thresholds (ng/L to mg/L) are normally at lower concentrations than those for taste thresholds (μg/L - g/L).

The most common approach to measuring all four of the above thresholds is through discrimination testing (Lawless and Heymann, 1999). An Ascending Forced Choice (AFC) test involves presenting panellists with a series of difference tests, with each round of testing presented in an ascending order of stimulus concentration. A panellist’s threshold is determined by identifying the point at which they accurately and consistently respond to the stimuli concentration. In order to provide some familiarity with the aroma or taste to be discriminated, a warm-up example may be given at a supra-threshold concentration (sufficient strength for the compound to be perceived).

The most common difference test is the triangle test. Each subject is presented with three random coded samples. Subjects are informed that two of the samples are identical and one is different. The subject tastes each product from left to right and selects the sample they perceive as different from the other two (Meilgaard, 2007).

Another difference test is the Same/Different Test, and a specific variation of this is *R*-Index, a signal detection method (Bi and O'Mahony, 1995). This test is used if there are many samples to be tested, which presents a high potential for sensory overload or fatigue. The advantage of this signal detection methodology is that it allows separation of the judge's sensitivity from the response bias (Lawless and Heymann, 1999). *R*-Index method takes into consideration the noise or background of a sample which reduces this response bias.

There are some limitations with threshold testing that need to be considered. The sensory capability of panellists can change with mood, time of day, age, sex, genetic differences, and hunger (Section 1.1.2.1). In addition, the background matrix of compounds within the sample can have considerable impact on the assessment results if these matrix compounds introduce adaption, synergistic, or masking effects to the perception of sensory stimulus (described below).

Many chemists use detection thresholds to determine a chemical compound's potential impact on a flavour profile. Methods such as Aroma Extract Dilution Analysis (AEDA) consider the level of detection threshold and compound concentration to suggest the degree of potential impact each compound has within a matrix, such as wine. This approach does not take into account any synergistic and/or masking effects of other volatile and non volatile compounds present in the mixture.

Atanasova et al (2005) also suggest that the presence of a compound in a matrix at concentrations above its detection threshold does not necessarily infer that the compound can be assumed to be an impact compound within that matrix. Similarly, it is not always the case that the highest concentration within a mixture has the most impact. (Bargmann, 2006). When measuring perception of flavour, masking and synergistic effects need to be considered. Synergism is described as when a compound is perceived as more intense in combination with another compound or mixture, then when it is perceived in solution by itself (Lawless and Heymann, 1999). Conversely, masking occurs when a compound is perceived as less intense in combination with another compound or mixture, then when it is evaluated by itself. Masking appears more often in complex mixtures (Atanasova et al., 2005). Ethanol in wine was shown to reduce the perception of esters (Escudero et al., 2007) as well as enhance bitterness and sweetness (Nurgel and Pickering, 2005; 2006). The taste of sweet has been proven to be enhanced by strawberry and lemon flavours (Frank, 2002).

Determining which compounds may be exerting a masking effect and which compounds may be exerting a synergist effect is difficult, especially in complex mixtures such as wine. A complete interpretation of the human perception of a wine's complex mixture would require comprehensive knowledge of the perceived intensities for each compound in the mixture, obtained from sensory and chemical data, along with a measurement of any masking and synergistic effects.

1.5 Principal Aims

Sensory evaluation using a trained panel is a valuable tool for a comprehensive understanding of flavour, more specifically, wine flavour. A trained panel for New Zealand Sauvignon blanc wine was used for the basis of all my research in this thesis.

There are three different aspects to this research. The first study focuses on a fuller understanding of trained panel motivation in order to be able to inspire our panellists to perform to the best of their abilities.

The second study uses the trained sensory panel to characterise and quantify flavours in New Zealand Sauvignon blanc wine. Was MIBP, which imparted a green flavour, the sole factor that could explain New Zealand Sauvignon blanc having a 'Marlborough style'? What contribution to New Zealand Sauvignon blanc wine flavour do the aromatic thiols have? What are the flavours that are exemplified in New Zealand Sauvignon blanc wine? Are there regional differences within New Zealand? The use of sensory data, in conjunction with chemical and consumer data will yield a more complete understanding of the distinctive flavours in New Zealand Sauvignon blanc wine.

The final study explores the interactions of different New Zealand Sauvignon blanc wine compounds and their effects on human perception. This was to improve understanding of the New Zealand Sauvignon blanc wine matrix.

The specific goals of my project were:

- To develop a tool for panel leaders to use in the measurement of panel motivation. This tool will be a survey that will be given to trained panellists to measure their intrinsic motivation. The longer term aim of this type of research would be to improve the quality of trained panel data through

understanding trained panellists' drivers, such as intrinsic and extrinsic motivation.

- To define the flavours of New Zealand Sauvignon blanc wine using sensory evaluation, chemical analysis, and consumer preference studies. A sensory lexicon was created and correlated to three key flavour compounds, as well as to the evaluation of New Zealand consumer preferences for Sauvignon blanc wine. The ultimate aim was to determine if Marlborough New Zealand Sauvignon blanc was different/distinctive from other international/national Sauvignon blanc wines, using these three measurements (sensory, chemical and consumer data).

- To measure the human odour detection threshold of different concentrations of four principal aroma compounds in New Zealand Sauvignon blanc wine, in the presence of three white wine polyphenols. The aim of this segment of the research was to increase the understanding of the interactions of chemical compounds present in wine. The ultimate goal was to determine whether aroma compounds were being synergized or masked in the presence of polyphenolic compounds.

CHAPTER 2

EFFECTS AND INFLUENCES OF MOTIVATION ON TRAINED PANELLISTS[1]

2.1 Introduction

Sensory scientists control external factors such as noise in the booths, external odours and lighting in order to reduce bias in the data collection process (Lawless & Heymann, 1999; Section 1.1.2). The reduction of extraneous audio and visual distraction allows panellists to focus on the product being evaluated, reducing external bias, and improving the accuracy of the data. In addition to controlling physical factors, sensory scientists also consider the control of psychological factors. As human beings, panellists are affected by certain psychological influences, including stimulus error, habituation error, logical error, and contrast error (Meilgaard et al., 2007). Sensory scientists are aware of these influences and attempt to minimize their psychological effects through the presentation of samples in randomised order, limiting the amount of information panellists receive regarding the samples, and performing tests in double-blind situations (Lund, 2007).

One psychological factor that has been determined to have an effect on performance is panellist motivation. Sensory scientists have been trained to regard panellists' motivation as crucial to the success of the panel, and have found that an interested panel is more effective than a disinterested panel (Meilgaard et al., 2007). More recently, Moskowitz et al. (2005) stated that the panel leader plays a critical role in maintaining panellists' motivation. Word and Gress (1981) suggested exploring the effect on motivation in response to different reward systems, such as telling panellists they have performed well, giving them a certificate, or monetarily rewarding them.

Several researchers examined whether feedback motivates the panellists to perform better (Armstrong et al., 1996; Marchisano et al., 2000). Marchisano and co-workers (2000) found that giving panellists feedback in a recognition or identification test had a positive effect on performance, whereas feedback on triangle tests showed no

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effect, and feedback in a scaling test had a negative effect. Findlay et al. (2006) used computerized feedback, not to motivate, but to shorten training time. Most of this literature was mainly speculative. Aside from considering the effects of performance feedback, none of the research considered the role of feedback in relationship to the motivation of panellists. The current study was guided from other research disciplines in psychology, sports training, and education literature, particularly when applicable to the concepts of trained panellists' motivation.

Psychology literature indicates that sizable amounts of confidence and motivation lead to improved performance. Deci and Ryan (1985, 2000) presented a self-determination theory that has been generally accepted in psychology and sports psychology research. Their theory uses motivation orientation to explain the degree of self-determined behaviour regulation, and maintains that the self-regulating nature of intrinsic motivation leads to consistently high levels of performance behaviour. The opposite behaviour would be amotivation (lack of motivation). Extrinsic motivation lies between these two extremes. Extrinsic motivation occurs when people do something in response to an external influence, such as payment, or when someone important to them wants them to complete the task.

Deci and Ryan (1985, 2000) maintained that the achievement of high performance levels relied on three factors - competence, autonomy and relatedness. It is anticipated that in terms of sensory panels, each of these three factors could be manipulated to improve motivation. Competence requires a level of self-confidence, which can be defined as "cognitions that one is up to the task and able to give one's best possible performance" (Stoeber et al., 2007). The panellist and the panel leader can each play a role in improving and promoting the panellist's self-confidence. A sense of autonomy can be created if a panellist feels they are performing a task because they want to, not because they are compelled by external factors. Finally, a person needs to feel connected to the group by developing a sense of value as a contributing member, thus satisfying the need for relatedness. In summary, a person will be motivated if they have the ability to perform the task, feel that they have some control in performing the task, and that they have some relationship to the group involved in performing the task.

An example can be shown in sports psychology. Psychologists believe that people are more likely to perform better if they are self-determined, rather than if they are extrinsically motivated or amotivated (LaVoi, 2007). Consider the child who enjoys competitive swimming and practices faithfully, versus the child who must be

compelled to practice. The child who voluntarily spends more time at practice would more likely become the better swimmer (Deci & Ryan, 2000). If panellists are intrinsically motivated to be trained panellists, they may be more likely to improve their performance as panellists (LaVoi, 2007).

Sports research literature also emphasises the motivating role of a coach who displays confidence, uses positive and persuasive language, and verbal rewards (Weinburg and Jackson, 1990). When a coach uses these motivational tools, the athlete's performance improves (Hollembeak and Amorose, 2005; Kais and Raudsepp, 2004; Katz and Assor, 2007; Mamassis and Doganis, 2004; Vansteenkiste et al., 2007; Vierling et al., 2007; Weinberg et al., 1992). Similar to the demand put on athletes, panellists must also consistently perform on command and to the best of their abilities, regardless of circumstances. The success of a sensory panel is dependent on the role of the panel leader in maintaining panellists' motivation (Moskowitz et al., 2005). The goal of a sports coach or panel leader is to create an environment that increases confidence and performance while preventing stress, anxiety, tension and burn out (Amorose & Anderson-Butcher, 2007).

Education research literature also discusses the balanced relationship between motivation and challenge. Without an appropriate amount of challenge, there is an increased risk that the performer could be discouraged rather than motivated by the challenge (Stoeber & Rambow, 2007). By analogy, we might expect that if a panellist is unable to recognise a specific sensory attribute they may become less motivated to continue the task, perceiving the challenge as too great. Equally, if the challenge is too low, the panellist may become bored. This circumstance might occur with panellists that have been on a panel for a long time - they may gradually lose motivation and interest as familiar panel work becomes routine, and thus perhaps less challenging.

This research in this Chapter used two surveys to address the following questions:

1. What were the initial and subsequent drivers that motivated trained panellists?

2. Were trained panellists intrinsically motivated?

3. What differences in motivation were found between external panels and internal panels?

4. What differences in motivation were found between new panellists and experienced panellists?

2.2 Materials and Methods

2.2.1 Survey 1 - Factors that inspire people to become and remain panellists

The aim of Survey 1 was to determine what factors inspired people to become panellists and what factors motivated them to remain panellists. Seven trained panels were surveyed (n= 74). Panellist age ranged from 25 to 65 years, and trained panel experience ranged from 1 year to more than 10 years. Survey 1 was administered to all panellists prior to their training session in December 2006. Descriptive analysis of specific products listed in Table 2.1 was the primary duty of Survey 1 panellists. These panellists were also involved in some difference testing. All panel leaders reported incorporating some form of panellist's performance feedback during panel work.

The panellists were asked to rank 10 motivational factors (Table 2.2), both intrinsic and extrinsic, that could have influenced their decision to become a panellist. Panellists were asked to rank all factors, giving a ranking of "1" to the most important factor through "10" as the least important factor. The questionnaires were filled out in individual booths prior to a standard training session. The panellists were instructed that the main goal of the research was to elicit their honest opinions and that there were no right or wrong answers. To ensure panellist anonymity, the use of identifying names or codes was omitted. The panellists were informed that this survey was part of study being done on many trained panels. Panellists were given the option of electing not to participate in the survey. The response rate was 100%. Experienced panellists were asked to remember back to what influenced them to become a panellist. Most of the experienced panellists did not express difficulty with remembering why they were inspired to become a panellist, but it is important to bear in mind that memories can be altered over time. Survey 1 was analysed for significant differences at $P \leq 0.05$ using the Basker Ranking Sum Table (Basker, 1988).

Table 2.1. Details about each panel used in Survey 1 and 2. Details include country of origin, type of panel, and products the panel tested.

Panel #	Country of origin	Type of panel	Products tested by panel
Survey 1			
1-6	New Zealand	External	Dairy products
7	New Zealand	External	Fruit and fruit products (i.e. wine)
Survey 2			
1	New Zealand	External	Dairy products
2	New Zealand	External	Dairy products
3	New Zealand	Internal	Dairy products
4	New Zealand	External	Fruit and fruit products (i.e. wine)
5	Spain	Internal	Fruit
6	Australia	Internal	Beer
7	USA	External	Processed products

Table 2.2. Factors that trained panellists (n=74) were asked to rate in order of importance as to what inspired them to become a panellist and what inspires them to remain a panellist.

Factor	Type of Factor*
Extra income	Extrinsic
General interest in food	Intrinsic
Interest in new foods	Intrinsic
Social interaction	Intrinsic
Intellectual stimulation	Intrinsic
Friend/ family was a panellist	Extrinsic
Recommended by a friend (become a panellist only)	Extrinsic
Something I do well	Intrinsic
I enjoy it (remain a panellist only)	Intrinsic
Promote research	Extrinsic
Prestige	Extrinsic

*Based on definitions in Deci & Ryan, 2000

2.2.2 Survey 2 – Intrinsic motivation survey

The aim of Survey 2 was to measure trained panellists' intrinsic motivation. Intrinsic Motivation Inventory (IMI) is a method of gauging a participant's subjective experience of an activity such as trained panel work. The original IMI was developed by Ryan et al. (1983) with 27 questions. McAuley et al. (1989) shortened the original IMI version by omitting redundant questions. Other researchers have used this short version IMI in measuring athletes' intrinsic motivation (Vierling et al., 2007).

Survey 2 was adapted from the modified IMI developed by McAuley et al. (1989) for athletes, so as to be applicable to the motivation of trained panels (Table 2.3). Survey 2 measured factors which intrinsically motivate people to serve as a panellist intrinsically (e.g. enjoyment or importance to self), as opposed to extrinsically motivating them, (e.g. income or praise). Survey 2 assessed five parameters of intrinsic motivation: interest/enjoyment, competence, value/usefulness, pressure/tension, and choice. The Survey 2 statements rated by the panellists are listed in Table 2.3. Seven trained panels (n=108) from five companies/universities in four countries were surveyed (Table 2.1). All the panels from New Zealand who participated in Survey 2 also participated in Survey 1 as shown in Table 2.1. Survey 2 was administered to the seven panels between February to May 2007, before their training sessions. Panel leaders in Survey 2 reported regularly incorporating some form of panellist's performance feedback during panel work.

Panels were comprised of either internal or external panellists. Internal panellists were company employees who considered their participation in panel sessions to be a compulsory requirement of their job. In contrast, external panellists were volunteers who were primarily recruited from outside the company, and they were financially compensated for their service as panellists. As in Survey 1, descriptive analysis of specific products listed in Table 1 was the primary duty of Survey 2 panellists. The panellists were asked to rate the statements on a 7-point category scale with the end points anchored at "not at all true" (0) and "very true" (6). A one-way Analysis of Variance (ANOVA) was measured using the Generalised Linear Model (GLM).

Table 2.3. Survey 2 modified Intrinsic Motivation Inventory Survey (McAuley et al., 1989) completed by trained panellists (n=108). Panellists scored on a 7-point category scale scale [not at all true (0) to very true (6)].

IMI Statement	Category
While I'm on the panel, I think about how much I enjoy it	Interest
I do not feel at all nervous about doing panel work	Pressure
I believe this panel work is of some value to me	Value/Usefulness
I think I am pretty good at my job on the panel	Competence
I find my panel work very interesting	Interest
I feel tense while doing panel work	Pressure
I think I do my job pretty well, compared to other panellists	Competence
Doing panel work is fun	Interest
I am willing to do this panel work because it has some value to me	Value/Usefulness
I feel relaxed with doing panel work	Pressure
I enjoy doing panel work very much	Interest
I don't really have a choice about doing panel work	Choice
I am satisfied with my performance on the panel	Competence
I am anxious while doing panel work	Pressure
I believe doing panel work is beneficial to me	Value/Usefulness
I think panel work is very boring	Interest
I feel like I am doing what I want to do while I do panel work	Choice
I feel pretty skilled at panel work	Competence
I think panel work is very interesting	Interest
I think this is an important job	Value/Usefulness
I feel pressured while doing panel work	Pressure
I feel like I have to do panel work	Interest
I would describe panel work as very enjoyable	Interest
I do panel work because I have no choice	Choice
After working on the panel for a while, I feel pretty competent	Competence

2.3 Results

2.3.1 Survey 1 - Factors that inspire people to become and remain panellists

Based on the panellists' rankings from Survey 1, the most important factor in inspiring people to become a panellist was *Income* (Figure 2.1). However, this ranking was not statistically significantly higher ($P \leq 0.05$) than the ranking for *general interest in food* and *social interaction,* in inspiring people to become panellists. This result shows that intrinsic factors such as *social interaction* and *interest in food* were just as important as *income*, an extrinsic factor, in motivating people to become panellists.

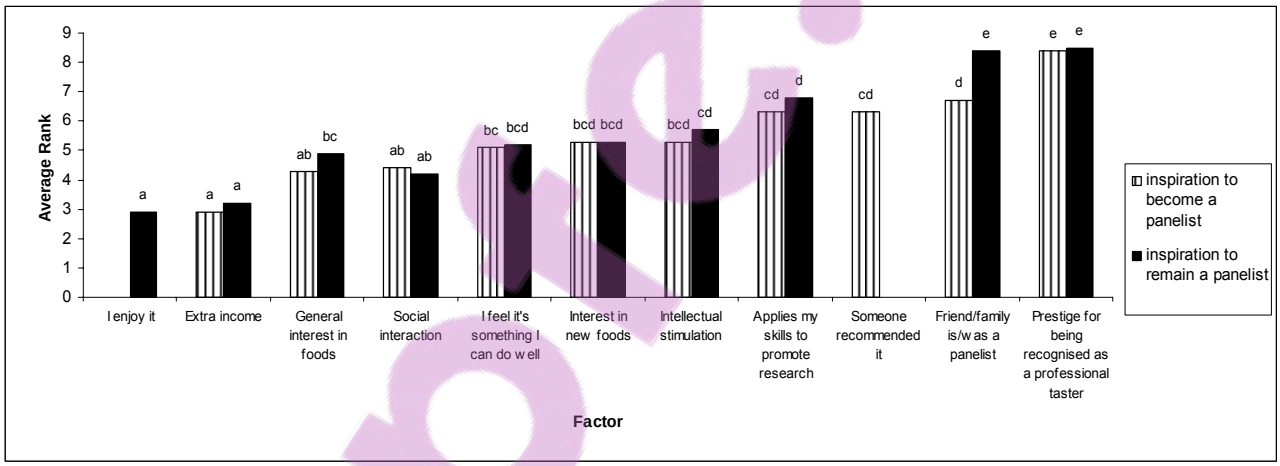

Figure 2.1. Factors that inspire people to become and remain panellists (n=74). Significant comparisons were made within each question ($P \leq 0.05$). The lower the rank indicates a more important the factor.

The most important factors found for inspiring people to remain panellists were *enjoyment* and *income,* with no statistically significant difference between these two factors ($P \leq 0.05$), indicating that the intrinsic factor of enjoyment was just as important as payment in retaining panellists. Two other intrinsic factors, a *general interest in foods* and *social interaction* were also important factors that inspired people to continue working as panellists.

2.3.2 Survey 2 – Measurement of panellists' intrinsic motivation in relationship to panel type and panellist's experience

Survey 2 was divided into five different parameters - *interest, competence, pressure, value/usefulness* and *choice*. Factor analyses showed that there were four main factors (Table 2.4). Factor 1 accounted for the largest variance in the data (29.2%), and was found to consist of both the *interest* and *value/usefulness* parameters, indicating a correlation between these two parameters. In the literature, *interest* and *value* are cited as being among the most important parameters in sustaining intrinsic motivation (McAuley et al., 1989). *Choice* was the primary component of Factor 2 (17.4%). *Competence* was the primary component of Factor 3 (14.2%), and *pressure* was the primary component of Factor 4 (8.4%) (Table 2.4).

Each statement of Survey 2 was analysed by the panel type (internal or external) and the respondent's length of time serving as a panellist. Means and *P* values of panellists' responses to Survey 2 are listed in Table 2.5 and 2.6, respectively.

2.3.2.1 Effect of panel type - Internal v. external panels

The panel type had a significant effect on the factors related to *interest* (Table 2.5). External panellists found panel work *more interesting* ($P \leq 0.001$), *more fun* ($P \leq 0.01$) and *more enjoyable* ($P \leq 0.001$) than internal panellists. *Interest* is a key factor in fostering intrinsic motivation (McAuley et al., 1989).

The response from internal panellists indicated they had less *choice* about doing their job (panel work) than external panellists did ($P \leq 0.001$). While the internal panellists perceived they had some *choice* in performing the task, their mean scores were significantly higher than those of the external panellists for all the statements related to *not having a choice to do panel work* ($P \leq 0.001$) (Table 2.5). This result might be a consequence of their mandatory conditions of employment. The perceived lack of choice reduces their sense of autonomy and consequently may decrease their intrinsic motivation. Compared with internal panellists, external panellists felt that panel work had more *value* ($P \leq 0.05$) and was more beneficial to them ($P \leq 0.01$). They also thought they were *better at their work* ($P \leq 0.01$) and more *skilled* ($P \leq 0.001$) (Table 2.5). These factors have been shown in the literature to contribute to higher quality of data through pride in their work (Ryan et al., 1983).

Table 2.4. Factor analysis (using varimax rotation) of modified Intrinsic Motivation Inventory Survey from seven different trained sensory panels (n = 108).

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Interest/enjoyment				
While I'm doing panel work, I think about how much I enjoy	1.258	-0.142	-0.242	-0.042
I find panel work very interesting	1.177	-0.297	-0.190	0.094
Doing panel work is fun	1.207	-0.191	-0.287	0.273
I enjoy doing my job very much	0.998	-0.070	-0.400	0.099
I think panel work is very boring	-0.374	0.842	-0.095	-0.170
I think panel work is very interesting	1.215	-0.364	-0.267	0.021
I would describe panel work as very enjoyable	1.065	-0.547	-0.329	-0.045
Pressure/tension				
I do not feel at all nervous about doing panel work	0.532	0.343	-0.372	1.225
I feel tense while doing panel work	0.212	0.357	-0.024	-0.940
I feel relaxed with doing panel work	0.476	0.060	-0.458	0.776
I am anxious while doing panel work	0.090	0.270	0.199	-0.728
I feel pressured while doing panel work	-0.213	0.695	-0.115	-0.806
Value/usefulness				
I believe this panel work is of some value to me	1.109	0.097	-0.093	0.122
I am willing to do this panel work because it has some value to me	1.202	0.012	-0.129	0.132
I believe doing panel work is beneficial to me	1.287	-0.010	-0.221	0.069
I think this is an important job	0.677	0.038	-0.363	0.029
Competence				
I think I am pretty good at panel work	0.513	0.141	-0.950	0.239
I think I do my job pretty well, compared to other panellists	0.293	0.540	-1.616	0.042
I am satisfied with my performance at panel work	0.258	0.151	-0.891	0.287
I feel pretty skilled at panel work	0.493	0.102	-1.147	0.154
After doing panel work for a while, I feel pretty competent	0.183	-0.202	-0.930	0.028
Choice				
I don't really have a choice about doing my job	0.021	1.638	-0.093	-0.042
I feel like I am doing what I want to do while I do panel work	1.261	-0.195	-0.299	0.015
I feel like I have to do panel work	-0.210	1.591	-0.149	-0.137
I do panel work because I have no choice	-0.191	1.325	-0.122	-0.265
Variance	15.936	9.499	7.754	4.585
% Variance	0.292	0.174	0.142	0.084

Table 2.5. Sensory panels' mean scores and *P* values from responses to Survey 2 - External vs. internal panel (n=108). Panellists scored on a 7-point category scale [not at all true (0) to very true (6)].

Factor	*P* values	Mean Scores*	
Interest/enjoyment		**External Panel** n=76	**Internal Panel** n=32
While I'm doing panel work, I think about how much I enjoy it	0.002	4.46a	3.38b
I find panel work very interesting	<0.001	5.63a	4.56b
Doing panel work is fun	0.002	5.50a	4.44b
I enjoy doing panel very much	<0.001	5.68a	4.63b
I think panel work is very boring	0.009	1.51b	2.31a
I think panel work is very interesting	<0.001	5.57a	4.27b
I would describe panel work as very enjoyable	<0.001	5.42a	4.12b
Pressure/tension			
I do not feel at all nervous about doing panel work	0.690	4.96	5.22
I feel tense while doing panel work	0.365	2.05	1.88
I feel relaxed with doing panel work	0.279	5.42	5.28
I am anxious while doing panel work	0.680	1.93	1.94
I feel pressured while doing panel work	0.271	2.07	2.45
Value/usefulness			
I believe this panel work is of some value to me	0.219	5.24	4.84
I am willing to do this panel work because it has some value to me	0.020	5.11a	4.31b
I believe doing panel work is beneficial to me	0.006	5.16a	4.25b
I think this is an important job	0.284	5.67	5.50
Competence			
I think I am pretty good at panel work	0.025	5.08a	4.56b
I think I do my job pretty well, compared to other panellists	0.690	3.99	3.84
I am satisfied with my performance at panel work	0.424	5.07	4.78
I feel pretty skilled at panel work	<0.001	5.11a	4.08b
After doing panel work for a while, I feel pretty competent	0.067	5.21	4.67
Choice			
I don't really have a choice about doing my panel work	<0.001	1.54b	3.63a
I feel like I am doing what I want to do while I do panel work	0.002	4.81a	3.78b
I feel like I have to do panel work	<0.001	1.42ba	3.55a
I do panel work because I have no choice	0.001	1.36b	2.60a

*Letters that are different within a row are significantly different at *P*-value stated.

The type of panel had no effect on the *tension* or *pressure* that the panellists felt while performing panel work. They were generally relaxed and not anxious or tense while doing panel work.

2.3.2.2 Effect of years working as a panellist

The number of years that people worked as panellists had a significant effect on their perceived competence. Please note that the sample sizes are too small to show significant results and therefore must be regarded as trends. Panellists who had been working for 1 year or less had a lower opinion of their personal competence than the panellists who had worked 10 years or more ($P \leq 0.048$), and less experienced panellists did not think their competence had increased with time compared with more experienced panellists ($P \leq 0.01$) (Table 2.6). The new panellists (<1 year) and those with 5-7 years of panel experience were less satisfied with their performance and felt less competent than panellists with 8-10 years of experience ($P<0.026$ and $P<0.001$, respectively). These results show that panel leaders may need to focus on giving new panellists the skills they require to begin building their perceived competence.

Panellists with 8 or more years of experience felt they were the most skilled at panel work ($P \leq 0.001$) compared with all other experience levels. This may indicate that panellists who make it through 7 years of panel work may reach a high level of confidence in their panel skills. On the other hand, those panellists who were not confident at 5-7 years may have quit the panel, increasing the percentage of confident panellists in the group that have more than 8 years of experience.

When looking at the *interest* category, panellists with 5-7 years of experience enjoyed their jobs the least compared with other panellists ($P \leq 0.015$). For *value/usefulness*, panellists with 8-10 years of experience were less likely to agree that panel work was of some value to them ($P \leq 0.009$) and that it was beneficial to them ($P<0.023$). Panel leaders may need to focus on helping more experienced panellists understand the ongoing value of their work.

A longitudinal study of panellists over several years would yield a better understanding of how experience affects their confidence in their performance. There could have been confounding effects with the type of panel and experience level, but the experience range of the external panel was similar to the experience range of the internal panel. It would be expected this would limit the confounding effect.

Table 2.6. Sensory panels' mean scores and *P* values from responses to Survey 2 - Length of time serving as panellists (years) (n=108). Panellists scored on a 7-point category scale [not at all true (0) to very true (6)].

Factor	*P* values	Length of time working as panellists Mean Scores*				
Interest/enjoyment		**< 1 y** n=13	**2-4 y** n=28	**5-7 y** n=25	**8-10 y** n=17	**>10 y** n=25
While I'm doing panel work, I think about how much I enjoy it	0.795	4.23	3.96	4.28	4.12	4.08
I find panel work very interesting	0.823	5.62	5.32	5.12	5.24	5.42
Doing panel work is fun	0.554	5.38	5.32	4.84	5.18	5.29
I enjoy doing my job very much	0.081	5.77	5.11	4.96	5.59	5.71
I think panel work is very boring	0.234	1.46	1.64	1.76	1.41	2.25
I think panel work is very interesting	0.161	5.77	5.29	4.72	5.24	5.19
I would describe panel work as very enjoyable	0.465	5.73	5.15	4.72	4.88	5.15
Pressure/tension						
I do not feel at all nervous about doing panel work	0.884	5.69	5.04	4.76	5.00	4.96
I feel tense while doing panel work	0.233	2.00	2.04	2.40	1.47	1.92
I feel relaxed with doing panel work	0.654	5.54	5.25	5.12	5.41	5.67
I am anxious while doing panel work	0.081	2.38	1.75	2.24	1.53	1.88
I feel pressured while doing panel work	0.399	2.45	2.22	1.92	1.82	2.54
Value/usefulness						
I believe this panel work is of some value to me	0.014	5.00ab	5.29ab	4.96ab	4.29b	5.79a
I am willing to do this panel work because it has some value to me	0.410	4.92	4.93	4.76	4.41	5.25
I believe doing panel work is beneficial to me	0.076	5.08ab	5.07ab	4.80ab	4.06b	5.21a
I think this is an important job	0.179	5.92	5.54	5.28	5.47	6.04
Competence						
I think I am pretty good at panel work	0.002	4.15b	4.86b	4.64b	4.82b	5.75a
I think I do my job pretty well, compared to other panellists	0.049	3.00b	3.79ab	3.76ab	3.94ab	4.75a
I am satisfied with my performance at panel work	0.021	4.54b	4.79ab	4.72ab	5.65a	5.21ab
I feel pretty skilled at panel work	<0.001	3.77b	4.54b	4.24b	5.59a	5.65a
After doing panel work for a while, I feel pretty competent	0.008	4.00b	5.04ab	4.80ab	5.35ab	5.56a
Choice						
I don't really have a choice about doing panel work	0.032	1.77	1.64	2.28	1.82	3.13
I feel like I am doing what I want to do while I do panel work	0.340	4.77	3.96	4.48	4.65	4.88
I feel like I have to do panel work	0.505	2.00	1.67	2.16	1.59	2.46
I do panel work because I have no choice	0.784	1.55	1.59	1.60	1.59	2.10

*Letters that are different within a row are significantly different at *P*-value stated.

2.4 Discussion

2.4.1 Factors that motivate panellists

Sensory scientists know that financial compensation motivates panellists (Word and Gress, 1981); this was shown in Survey 1. However, in this survey, compensation was not found to be statistically significantly more important than a panellist's interest in food, which is an intrinsic motivating factor. As an external motivation factor, compensation does not engender self-regulating behaviour and therefore may not sustain consistent levels of performance.

When a task engages a person's intrinsic motivation, that person is more likely perform the task. Deci and Ryan (2000) provide the example of a person who enjoys playing the piano and is motivated by the sheer pleasure of the task. However, if that person is forced to play or overwhelmed by technical difficulties within the piece, they might begin to perceive playing the piano as a chore and not persist with the task. Intrinsic motivation requires autonomy (not feeling forced) and competence (being able to complete the task), and an appropriate level of challenge. Panellists who rated *I remain a panellist because I enjoy it* did so because they were intrinsically motivated. They felt their decision to be a panellist was an autonomous choice, and that they were able to complete the task and do it well. If a person participates in a panel because they are motivated by an extrinsic factor (money), then they may be less likely to perform consistently well (Deci and Ryan, 2000).

2.4.2 Autonomy

When deciding what type of trained panel to establish, companies must often consider which panel type is the most cost effective, yet enables them to make appropriate business decisions. Companies may not want, or cannot afford, the extra salary costs associated with external panellists. Although some companies might have a large pool of employees from which to gather sufficient numbers of volunteers, this convenience may not be possible for small or medium sized companies, and it may be necessary to assign employees to internal sensory panels. However, internal panels are not necessarily the optimum alternative solution.

Comparisons of the IMI survey comparing data from external and internal panels showed that external panels had higher scores for intrinsic motivation than internal panels. The external panellists had experienced autonomous choice in their decision to apply and serve on panels. In contrast, internal panellists might not have

anticipated any requirements to serve on panels as a condition of their employment. Consequently, they might consider any time spent as a panellist as an additional, non-negotiated requirement to the job they agreed to do. Our measurement of lower intrinsic motivational scores for this group of internal panellists reflects their attitude that participation in panels is an externally imposed demand on their time, reducing their perceptions of autonomy and possibly their motivation to perform. Less reliable data could result in poor business decisions and higher costs. To mitigate these de-motivational influences, internal panellists could be allowed some specific compensation (in lieu time, or some pay differential) for their participation in panel work. Internal panellists should also be given sufficient time to perform normal duties so as not to add stress from too little time to complete their current work load.

In situations where the use of internal panels is unavoidable, it is crucial for panel leaders to cultivate as much panellist autonomy as possible. Panel leaders can allow panellists to choose their preference of meeting times, or allow them flexibility in their session attendance. It should be noted that these allowances for panellist autonomy will introduce some complications to the statistical analysis of the data and may have an adverse impact on the operation of the panel. External panels might cost more but offer the advantages of intrinsically motivated panels (higher scores in *interest, choice, competency and value*), which should lead to reduced panellist turnover. External panels should provide improved levels of performance and more reliable data, so these advantages may ultimately be the lower cost option for improved data quality and increased panellist retention. Correlation of intrinsic motivation and panellist performance will need to be validated.

2.4.3 Competency

Perceived competence was evident in highly experienced panellists, compared with panellists having little or no experience. The experienced panellist (> 8 y) felt very competent. Stoeber, et al. (2007) stated that self confidence in a task can be highly associated to high levels of performance. Mastery of a task acquired through years of experience will build self confidence.

Among panellists who have been working for 5-7 years, the moderate scores in perceived competence possibly relate to the repetition and familiarity of panel related tasks, with a concomitant perception that these tasks offer reduced challenge. Panellists' boredom could lead to a reduced focus on the task with a resultant decrease in performance, and consequently negative effects on the panellists' self-

perception of task competency. Future work could correlate panellist age with years of experience, to determine if age has a relationship with perceived competency.

As could be expected, panellists with less than one year of experience felt they lacked competency compared with the more experienced panellists. The data suggest that after a year of experience, panellists gain confidence in their competency. It will be important in future research to verify if panellists' perception of competency positively correlates with their performance.

Positive and negative cues from the panel leader can affect certain panellists but will probably have a stronger influence on panellists with lower levels of intrinsic motivation. Previous research showed that when experienced panellists were given negative verbal cues, they responded positively, perceiving the negative feedback as a challenge, which in turn improved their competency and their performance levels (Lund, 2005). If a panellist lacks competency are more likely to have a negative impact and lead to poor performance (Appendix G).

The panel leader needs to be aware of appropriate levels of challenge. Reinboth, et al. (2004) confirmed that when a coach provided a training environment of autonomy and relatedness, and introduced challenge, this combination improved both the athlete's performance as well as the athlete's perceptions of their own competence. Panellist experience is also important to consider in examining motivation because motivation may decrease with continuing panellist experience as the panel work becomes less challenging, or less intrinsically motivating. Panel leaders need to be able to provide enough challenge such that the intrinsic motivation of 5- to 7-year experienced panellists is fostered, but not so much challenge that the newer panellists lose interest.

Understanding motivation is not only critical in trained panels but also with consumer panels. Frandsen et al. (2007) were able to motivate their consumers by creating a psychological challenge. Their Danish consumer panellists were initially unable to perceive a difference between two milk products via a difference test. In a subsequent session, researchers informed the consumer panellists that one product was a Danish milk and the other was a foreign milk, and asked the panellists to see if they could discern a difference. The difference test from this second session yielded a significant perceived distinction between the products. Apparently providing additional information to the panellists increased their ability to discern a difference

between the two products. This improved discerning ability could imply the consumers were more motivated to perceive a difference between the products.

2.4.4 Relatedness

The panel leader can greatly influence the panellists' feelings of relatedness as important and valuable members of the panel. Providing performance feedback, using positive verbal cues, and discussing the importance of accomplished panel goals are some of the tools a panel leader can use to foster panellists' experience of relatedness. Amorose and Anderson-Butcher (2007) found that those coaches who were supportive of an athlete facilitated that athlete's abilities to build and sustain intrinsic motivation. Further research should investigate the effects of a panel leader's positive influence in developing panellists that who feel supported and valued.

Feedback is an important tool that the panel leader can utilise in motivating panellists to increase their feeling of group relatedness. A study that evaluated the effects of coaches providing feedback to teachers showed that this feedback played a role in engaging the teachers in their student assessment task. Teachers were motivated to become involved with their student assessment duties through this coach involvement (Denton et al., 2007). With respect to panellists, this research would suggest that giving an individual feedback on their performance would be intrinsically motivating. If a panellist is genuinely interested in panel work, they will want to improve their performance just as a pianist who is passionate about playing will enjoy practicing, because it is improving their skill. Panel leader's feedback is a way to engage panellists and make them feel connected to the group. Feedback could come from summary reports, panel leaders and/or other panellists.

2.4.5 Panellist recruitment

Currently many sensory scientists screen new panellists for physiological acuity. Sensory scientists test for taste and odour acuity, but it may be beneficial to seek a motivation profile test that could be used when screening new panellists. Literature suggests that sensory scientists should advertise for panellists in food sections of newspapers and that good panellists should show a passion or interest in food (Stoer and Rodriguez, 2002), which our results show was an important intrinsic motivation factor for panellists. Through a screening questionnaire, a panel leader could

determine whether working with food is an interest of the panel. This would give information on whether there is the potential for intrinsic motivation to occur.

2.5 Conclusion

More research is needed for a better understanding of the relationship between panellist performance and their level of intrinsic motivation. Future research should focus on comparisons of levels of intrinsic motivation to determine this factor's effectiveness in panel performance directly. Longitudinal studies would aid in the understanding of the effects of panellists' experience. Collaborations, as conducted in data collection of Survey 1 and 2, might help in acquiring a larger sample size, removing the limitations of the usual 8-10 person panel.

A major outcome from the work recorded in this chapter is a tool for panel leaders to measure panellist motivation. With a comprehensive understanding of motivational factors the panel leader could tailor their approach for each panellist. Good panel leaders probably adapt their responses intuitively, but improving and defining this process could assist all panel leaders.

CHAPTER 3
NEW ZEALAND SAUVIGNON BLANC FLAVOUR CHARACTERISTICS: SENSORY, CHEMICAL AND CONSUMER ASPECTS[2]

3.1 Introduction

3.1.1 Regionality

The "typicity" for products has been the focus of recent research in Europe (Iaccarino et al. 2006, Martinez Carrasco et al. 2005). The term is used to convey those wine qualities and flavour characteristics that can be expected from a region, which is defined as "a broad geographic area distinguished by similar features" (http://www.merriam-webster.com/dictionary/Region). In this research a region is a named area of land. In France, the Appellation d'Origin Controlee (AOC) was established to regulate quality from the designated wine-producing regions. Geographic influences on wine sensory profiles have been investigated extensively, including studies with wines made from grape varietals such as Albarino (Vilanova and Vilarino, 2006; Vilanova et al., 2007), Touriga Nacional (Falque et al., 2004), Riesling (Fischer et al., 1999; Douglas et al., 2001), Chardonnay (Schlosser et al., 2005), and Pinot noir (Cliff and Dever, 1996). Through the evaluation of sensory characteristics and/or chemical compositions these studies have found regional or sub-regional differences among the wines. I was interested in determining differences among Sauvignon blanc from different geographical sources in terms of chemical composition and sensory profiles, in combination with consumer preferences. The current study also focused on wine from three regions within New Zealand and compared them with wines produced in five other countries.

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3.1.2 Sauvignon blanc flavour

Sauvignon blanc wine has distinctive sensory characteristics, both fruity (passionfruit, gooseberry, citrus, tropical) and green (capsicum, asparagus, grassy, leafy) (Cooper 2002). These descriptors have been attributed to key chemical aroma and flavour compounds occurring in the wine as discussed in Section 1.2.1. The thiols primarily contribute to the passionfruit, gooseberry, tropical, boxwood characteristics and the methoxypyrazines are associated with the green attributes in the Sauvignon blanc wine (Section 1.2.1).

One wine study on closure types and their subsequent effect on the chemical concentrations and flavours of Sauvignon blanc wines demonstrated that, after a year of storage, wines bottled under screwcap experienced very little change in flavour when compared with wines bottled under cork (Brajkovich et al. 2005). The wines with different closures were chemically analysed for thiols, oxygen and sulfur dioxide, and then sensorially assessed for six descriptive attributes (capsicum, sweet sweaty passionfruit, passionfruit skin/stalk, cat's urine, grassy, flinty/mineral). Francis and others (1994) compared Sauvignon blanc, Chardonnay, and Semillon juice through descriptive analysis. Since researchers in that study were evaluating unfermented grape juice, and thiols are only present in finished wine, the sensory attributes of thiols could not be examined. The Sauvignon blanc juice expressed a strong capsicum characteristic in comparison to the other varietal juices.

Winemakers' opinions of the Marlborough style wine were evaluated in a recent study by Parr and co-workers (2007). To strengthen the understanding of geographical influences on the flavour characteristics of New Zealand Sauvignon, the current study attempted to provide an objective, scientific correlation of sensorial evaluations with chemical results.

This research of New Zealand Sauvignon blanc began with a narrow assessment of Sauvignon blanc wines from the 2003 vintage. Lund et al (2005) looked at the sensory differences among 28 New Zealand Sauvignon blanc wines selected from the 2003 vintage and found significant differences between the six regions examined. Using six sensory attributes to evaluate each wine, the researchers found that Hawke's Bay Sauvignon blanc wines were high intensity in mineral flinty characteristics, whereas the Marlborough wines exhibited high intensity in sweet sweaty passionfruit and capsicum characteristics. The Wairarapa wines were found

to be higher intensity in cat's urine/boxwood characteristics. The study focused solely on different regions within New Zealand and did not include any comparative samples from overseas. The study revealed that some of the wines from specific New Zealand regions showed measurable differences in their flavour profiles. Based on the results from the New Zealand 2003 vintage, another 35 Sauvignon blanc wines from the New Zealand 2004 vintage were selected from these three regions. Sauvignon blanc wines used in the current study of the 2004 vintage were selected from regions that had shown flavour differences in the 2003 vintage wines (Lund et al. 2005).

Wine marketers and writers make the claim that Marlborough Sauvignon blanc has distinctive flavours compared with Sauvignon blanc wines produced from other regions (Cooper 2002). In the research presented here, commercially available wines were evaluated to investigate whether Marlborough Sauvignon blanc wine exhibits regionally distinctive flavours as compared with wines from France, Australia, South Africa, Spain, and the United States. Defining the sensory profiles of Sauvignon blanc will aid future researchers in understanding the flavours and the chemicals associated with these flavours. Ultimately this research may be employed to facilitate the use of chemical measurements to predict descriptive attributes of wine.

In 2004 export volumes have increased 15% and account for 47% of total wine sales (www.nzwinegrowers.co.nz). Marlborough Sauvignon blanc contributes significant revenue to the NZ economy. The ability to maintain a global position as a market leader for Sauvignon blanc is critical to the success of the New Zealand wine industry. Scientific exposition of the distinctive flavours of Marlborough Sauvignon blanc may give wine marketers the validity to substantiate their marketing claims, and thus benefit the New Zealand economy with increased export sales.

3.2 Materials and Methods

3.2.1 Wine

In order to provide a comprehensive sensory evaluation of Sauvignon blanc, and to promote a diverse elucidation of definitive flavour profiles, the sensory panel used descriptive analysis to define the sensory characteristics of 52 Sauvignon blanc wines from six countries. Of the 52 wines, 49 were analysed chemically, and eight

were selected for further assessment by a consumer panel. The wines were from New Zealand, France (Sancerre, Loire Valley, Bordeaux), Spain (Rueda), South Africa (Stellenbosch), Australia (South Australia, Western Australia, Victoria), and the United States (Napa valley CA, Russian River CA, Sonoma CA, Columbia River WA). Four to five wines from each country were included in the study, but only two wines could be acquired from Spain (Table 3.1). New Zealand was represented with wines from three distinct wine growing regions: Hawke's Bay and Wairarapa in the North Island, and Marlborough in the South Island. Wines were selected on the basis of being predominantly from the Sauvignon blanc grape (>90%). Most of the 52 wines were tank-fermented wine with little or no oak aging. However, one Hawke's Bay wine, one Australian wine, one American wine and two French wines had some oak barrel fermentation. Oak aging is not a common practice in the production of New Zealand Sauvignon blanc wines, but it is commonly used in the production of French Sauvignon blanc. Oak aging has been said to contribute flavours such as smoky, spice coconut, vanilla (Goode, 2006). Amerine and Roessler (1976) stated oak produces wine that is more 'complex and mellow'. Although oak aging might introduce a confounding effect on the interpretation of the results of this study, I chose to include a few oak aged samples in the descriptive analyses testing, as these wines represent a particular stylistic rendition of Sauvignon blanc available to consumers.

All the Southern hemisphere wines were selected from the 2004 vintage. The availability of wines from the Northern hemisphere at the time of this study was limited to wines from the 2003 vintage, with the exception of one French and two Spanish wines, which were from the 2004 vintage.

The retail price of the wines (sometimes used as a proxy for commercial assessment of quality) ranged from US$6 to US$20 a bottle, with the largest proportion of the wine prices falling between US$8 and US$14.

Standard chemical wine analysis was performed on all of the wines to attain residual sugar, ethanol, pH and titratable acidity (TA). Upon completion of the flavour sensory testing, flavour chemical component analyses were conducted on each wine. Wine samples were tested in triplicate for all analyses.

The eight wines chosen for the consumer study comprised a broad range of Sauvignon blanc wine styles, as delineated by the results of the previous descriptive analysis in the current study. Wines selections were sourced from four countries:

France, Australia, South Africa, and New Zealand, on the basis of their common commercial availability within the New Zealand market. New Zealand Sauvignon blanc was represented by wine samples from Hawke's Bay, Wairarapa, and Marlborough regions. Marlborough Sauvignon blanc dominates the New Zealand wine market, so three Marlborough wines were included for assessment by the consumer panel. It is important to note that all wines selected for the consumer study were chosen because they represented a distinctive regional flavour profile, and not necessarily because they represented what might be regarded as a "typical" regional flavour profile.

Table 3.1. Number of wines analysed by descriptive and chemical analysis in each region (n=52).

Regions	Quantity
New Zealand	
Marlborough	16
Wairarapa	7
Hawke's Bay	7*
South Africa	6
Stellenbosch	
Australia	5
South Australia	
Victoria	
Western Australia	
USA	5
Napa Valley, CA	
Russian River, CA	
Sonoma, CA	
Columbia River, WA	
France	4**
Bordeaux	
Loire Valley	
Sancerre	
Spain	2***
Rueda,	

*One wine was not chemically analysed.
**One additional wine was chemically analysed.
***Neither was chemically analysed.

3.2.2 Trained panellists

Fourteen people were selected for the final panel based on their performance for providing correct answers in screening tests. None of the panellists had prior experience in wine sensory assessment. The final panel was comprised of three males and eleven females, and panellists' ages ranged from 27 to 55 years. The panellists were paid an hourly wage. Panellists developed the lexicon and reference standards, following normal descriptive analysis as described in Sections 1.1 and 1.2.3. Panellists completed 70 hours of training in descriptive analyses and in the sensory evaluation of Sauvignon blanc wine.

3.2.3 Consumer panellists

Panellists were recruited on the basis that they wine consumers. Panellists' Sauvignon blanc consumption was evaluated but not used as a selective criterion for recruitment. I felt it was more important to understand the preferences and purchasing behaviours of a general wine consumer rather than limit the focus to only Sauvignon blanc wine consumers. Panellists were recruited from wine shops, from the HortResearch workplace, and by word of mouth. Remuneration for participating in the study consisted of a bottle of wine. The 109 consumers evaluated all eight wines chosen for the study.

3.2.4 Facility and evaluation

All sensory testing was performed in booths at the HortResearch Sensory and Consumer Science Facility in Mt Albert, Auckland, New Zealand as stated in Section 1.2.3. Trained panellists received 20 ml of each wine for testing while consumer panellists received 15 ml of each wine for testing. Both the trained and consumer panel were monadically served samples in a randomised presentation order. The trained panellists rated the intensity of each attribute from 'Absent' to 'Extreme' on an unstructured linescale (Appendix B). The consumer panel rated their overall liking of the each wine ('Dislike extremely' to 'Like extremely') on a 150-mm linescale (Appendix D). Panellists were permitted to re-taste samples if necessary. Consumers were also asked demographic and purchase behaviour questions.

Table 3.2. Sauvignon blanc sensory reference standards used in trained panel evaluations.

Lexicon	Reference Standards
Sweet sweaty passionfruit	2,000 ng/L 3MHA (Oxford Chemical)*
Capsicum	1,000 ng/L MIBP(Acros Organics)*
Cat's urine/boxwood	1,000 ng/L 4MMP (Oxford Chemical)*
Passionfruit skin/stalk	2,000 ng/L 3MH (Interchim)*
Grassy	28,800 ng/L cis hex-1-en-2-ol (Sigma)*
Flinty/Mineral	4,000 ng/L benzyl methyl thiol (Oxford Chemicals)*
Citrus	30 g 'Yen Ben' lemon plus 15 g 'Bear' lime soaked in base diluted base wine 30 min**
Bourbon	2,400 μg/L hexanol (Sigma)*
Apple lolly/candy	2.50 mg hexyl acetate (Sigma) /L*
Tropical	40 ml Golden Circle® Mango juice plus 40 ml Golden Circle Golden Pash drink plus 200 ml Just Juice® Mandarin Passionfruit juice**
Mint	25 mg/L cineole (Sigma)*
Fresh asparagus	50 ml steamed asparagus water**
Canned asparagus	10 ml Watties® canned asparagus juice*
Stonefruit	Canned Watties® apricot and peach juice soaked in diluted base wine 30 min (equal parts)**
Apple	70 g 'Sciros'/Pacific Rose™ apple peeled soaked in diluted base wine 30 min**
Snowpea	1,275 ng/L MIPP (Acros Organics)*

*Added to diluted base wine (50% Corban Sauvignon blanc and 50% water)
**Added equal parts to base wine (Corban Sauvignon blanc)

3.2.5 Descriptive analysis

Trained panellists evaluated the 52 wines in triplicate. Panellists evaluated 10 to 11 wines per session, with a 30-second break after each wine and a 5-minute break after every three wines to reduce sensory fatigue. Each panellist returned for 15 sessions so that an individual panellist tasted every wine. Variations were made to the presentation order of wine samples served concurrently to all panellists, and to the presentation order of subsequent replicate samples provided to individual panellists.

Assessing 52 wines within a single session cannot be reliably accomplished without encountering the deleterious effects of panellist sensory fatigue. Likewise, when the assessment of a large number of wine samples is scheduled to extend over the course of several panel sessions, there will be the challenge of getting every panellist to attend every session. An incomplete randomised block design was applied to manage these challenges. The panellists were given the samples randomly and the randomised samples were blocked by replication (1, 2, 3). The attributes and their reference standards evaluated by the panel are listed in Table 3.2.

3.2.6 Methoxypyrazines analysis (This analysis was conducted by Laura Nicolau's wine science chemistry team)

The quantification of MIBP and MIPP was performed according to the method described by Kotseridis and co-workers (1999). In brief, the organic phase of a triple extraction of 200 ml of wine (pH 8) with 1:1 diethyl ether:hexane is concentrated down to 100 µl and 2 µl are analysed by gas chromatography coupled with mass spectrometry using a capillary column BP20 (50 m x 220 µm x 0.25 µm). The modifications made to this initial method were: (1) the utilization of methoxy-3-([$^2H_3$]isobutyl)pyrazine as an internal standard instead of methoxy-3-([$^2H_2$]isobutyl)pyrazine, (2) the utilization of 2-methoxy-3-methylpyrazine as an internal standard for the quantification of MIPP.

The quantification ion of the methoxy-3-([$^2H_3$]isobutyl)pyrazine was ion m/z = 127; ions m/z = 154 and 169 were used as qualifiers. For 2-methoxy-3-methylpyrazine, the ion m/z = 124 was used as the quantifier and ion m/z = 106 as the qualifier. The quantification ions of the MIBP and MIPP were ions m/z 124 and 137 respectively, and the ions m/z 151, 164 and 124, 152, were respectively used as qualifiers.

The standard curve was prepared by adding increasing quantities of MIBP and MIPP to a Sauvignon Blanc wine (Marlborough, 2004 vintage): from 2 to 50 ng/L, to obtain eight different concentrations. The regression equation obtained was Y = 1077 X – 1.3699 with r^2 = 0.9957 for MIBP and Y = 1526.1X + 0.4395 with r^2 = 0.9991 for MIPP. Relative standard deviations of 4.8% and 6.2% were obtained for MIBP and MIPP respectively, by assessing ten samples of the same wine.

3.2.7 Volatile thiols (This analysis was conducted by Laura Nicolau's wine science chemistry team)

The method of Tominaga and co-workers (1998a) and modified in 2006 was used to determine the level of 3MHA and 3MH, using 4-methoxy-2-methyl-2-mercaptobutane as an internal standard. The thiols were extracted from 50 ml of wine using *p*-hydroxymercuribenzoic acid, which was then fixed onto an anion exchange column, before the thiols were eluted with cysteine and extracted into dichloromethane prior to concentration and manual injection of 2 µL onto an Agilent 6890N Gas Chromatograph (GC) with an Agilent 5973 MS detector. The thiols were separated on a 50 m BP20 capillary column (220 µm x 0.25 µm) using He carrier gas at 28 cm/s and an oven temperature ramping from 40 to 220°C for a 71 min run.

Standard curves were obtained by adding increasing quantities of the two volatile thiols to a Sauvignon Blanc wine (50-500 ng/L of 3MHA; 500-5000 ng/L of 3MH). The correlation coefficient (r^2) was 0.990 for 3MHA and 0.997 for 3MH. The reproducibility of the method was evaluated by repeating the analysis of the same Sauvignon Blanc wine six times under constant operating conditions. Relative standard deviations of 6% and 5% were obtained for 3MHA and 3MH, respectively. The methodology use for thiol extraction was developed by Tominaga and Dubourdieu (2006).

3.2.8 Statistical analysis

Analysis of variance (ANOVA) was determined using Residual Maximum Likelihood (REML), with region selected as the fixed effects and panellist/bottle + region/wine/bottle selected as random effects in Genstat Release 8.1 [(PC/Windows XP) Copyright 2006, Lawes Agricultural Trust (Rothamsted Experimental Station)]. Because of the unequal numbers of wines from each region, standard error of differences (SED) and least significant differences (LSD) vary for each pairwise comparison. Conservatives values SED and LSD are presented in Table 3.3.

Principal component analysis (PCA) and Canonical variate analysis (CVA) were employed using the fitted wine means for each of the 16 attributes in the descriptive analysis data (SAS Institute, Cary, NC). A one-way ANOVA was used to determine differences between the regional chemical concentration analysis and other standard chemical analysis, such as sugar content and pH, using Fisher's LSD with 95% confidence level ($P \leq 0.05$).

To determine the relationships between three chemical compounds and all sensory data, Partial Least Squared Regression (PLSR) was performed (The Unscrambler v9.1, Camo Process AS 2004). Three of the chemicals (3MHA, 3MH, MIBP) were found to contribute to the prediction of the sensory characteristics, but MIPP did not contribute and was therefore omitted from the PLSR analysis.

The overall liking scores collected from the wine consumers were analysed using a one-way ANOVA ($P \leq 0.05$) in Genstat. The preference map analysis was conducted in R (R Development Core Team, Vienna, Austria 2007) which took the individual scores of the preference data and projected them into the two-dimensional space of the sensory attributes. A Generalized Procrustes Analysis (GPA) was performed in R to correlate sensory and consumer data, to determine the different clusters of consumers for each flavour profile.

3.3 Results

3.3.1 Sensory analysis

The descriptive analysis data revealed that the Marlborough wines had distinctive sensory characteristics with intensity levels that exceeded those of the international wines (Table 3.3). Several of the attributes (grassy, apple candy, citrus and canned asparagus) did not show significant *P*-values among different regions. The lack of significance between regions for those attributes was compounded by the occurrence of wide variation in the attribute measurements of wine samples from within a single wine region. Consequently, wines from a specific region may not necessarily display homogenous sensory intensities for those particular attributes.

Table 3.3. Sensory attribute means in Sauvignon blanc wines (n=52) sampled from different regions.

REGION	MEAN INTENSITY FOR SENSORY ATTRIBUTES**							
	Sweet sweaty passion fruit	Cap-sicum	Cat's urine	Passion fruit skin/stalk	Grassy	Flinty/ mineral	Bour-bon	Apple candy
Australia	47.7 c	28.5	34.6 d	41.3 b	24.4	26.8 a	25.6 abc	28.0
France	46.5 c	30.0	39.6 bcd	42.7 b	24.2	30.9 a	26.3 abc	23.8
Hawke's Bay	51.9 bc	29.5	40.2 bcd	44.4 ab	22.3	28.0 a	24.1 bc	27.4
Marlborough	60.6 a	32.5	43.2 ab	48.1 a	22.7	20.3 b	18.4 d	25.8
South Africa	51.5 bc	28.8	41.2 abc	40.8 b	21.1	29.3 a	27.1 ab	25.6
Spain	60.2 ab	29.4	51.8 a	43.1 ab	19.6	28.7 ab	21.1 bcd	21.6
USA	47.9 c	28.7	36.9 cd	42.4 b	23.0	27.0 a	31.3 a	27.2
Wairarapa	57.5 ab	30.4	42.2 abc	45.3 ab	22.5	25.9 ab	21.0 cd	25.3
SED*	2.9	1.7	3.5	2	1.5	2.9	2.4	1.9
P-value	<0.001	0.010	0.004	<0.001	0.16	<0.001	<0.001	0.15
Std Deviation	29.2	25.5	28.8	25.8	20.7	25.4	23.4	29.1

REGION	MEAN INTENSITY FOR SENSORY ATTRIBUTES**							
	Tropical	Citrus	Mint	Canned aspara-gus	Fresh aspara-gus	Stone-fruit	Apple	Snow-pea
Australia	20.2 bc	37.7	18.3	9.1	10.7 bc	26.4 b	27.3 ab	11.4 ab
France	16.6 c	36.7	17.7	14.6	11.7 bc	28.9 ab	26.2 ab	10.2 ab
Hawke's Bay	21.6 bc	40.1	16.8	10.4	12.6 bc	29.4 ab	26.7 ab	11.7 ab
Marlborough	32.3 a	39.8	17.2	8.6	16.9 ab	32.8 a	29.4 ab	14.0 a
South Africa	19.1 bc	38.2	15.3	12.5	11.2 bc	26.4 b	24.4 b	12.2 ab
Spain	20.0 bc	36.1	14.9	5.2	13.4 bc	24.9 b	23.9 ab	6.7 b
USA	19.8 bc	34.6	16.1	11.4	8.8 c	28.5 ab	24.6 ab	10.0 ab
Wairarapa	25.5 b	40.5	15.3	13.5	19.8 a	31.8 ab	29.5 a	13.2 ab
SED*	3.3	2.4	1.1	2.9	2.7	2.2	2.2	1.9
P-value	<0.001	0.11	0.010	0.065	<0.001	<0.001	0.007	0.016
Std Deviation	23.3	26.6	18.3	25.8	19.6	22.8	22.1	16.2

*SED comparing regions with the largest sample size, Marlborough (n=16) and smallest sample size, Spain (n=2). This is a conservative value taking into account different replications between regions.

**Different letters in the same columns indicate significant difference ($P \leq 0.05$)

The principal component analysis (PCA) gives a pictorial relationship of the wines based on their sensory attributes (Figure 3.1). The PCA simplifies the interpretation of multivariate analyses by extracting two or three dimensions which display the maximum amount of variability amongst the data. Wines which are very similar appear close to each other. In comparison, Canonical Variate Analysis (CVA)

extracts the dimensions which display the maximum amount of variation between the groups of wines from different regions (Heymann and Noble 1989). The results of both the PCA and the CVA were consistent in identifying relevant regional attributes within the data (Figure 3.2).

With the exception of the wines from Hawke's Bay, New Zealand's regional wines were clearly distinguishable from the international wines (Figure 3.1a). Marlborough and Wairarapa wines showed high attribute intensities for fresh asparagus, sweet sweaty passionfruit, capsicum, passionfruit skin/stalk, tropical, stonefruit, and apple, which comprised most of the variation of the data shown on the x axis (Principal Component 1). In contrast, the wines from South Africa, France, Australia, the USA, and the Hawke's Bay region of New Zealand were characterised by attributes of bourbon, flinty/mineral and canned asparagus. The variation explained by Principal Component 1 (PC1) was 47.4%. On Principal Component 2 (PC2) (variation explained 14.1%), the wines on the bottom half of the graph (Figure 3.1) displayed more strongly the boxwood/ cat's urine attribute, while those wines at the top of the graph were more intense in the apple lolly/candy characteristics. To improve the clarity of the plotted data, attributes with joint correlation in PC1 and PC2 of less than 0.5 in absolute value were not labelled on the PCA graph. Although all attributes were included in the analyses, not all the attributes are displayed in Figure 3.1.

Principal Component 3 (PC3) (explaining an additional 9.7% variation) further clarified the data (Figure 3.1b). The attributes on PC1 are the same as in Figure 3.1a. PC 3 shows wines in the top half of the graph being separated from the others by the presence of asparagus notes (both canned and fresh). Wairarapa wines appeared to contain higher levels of both fresh and canned asparagus characteristics; the Marlborough wines had more fresh asparagus notes, and the international wines had more canned asparagus notes.

The ellipses in Figure 3.1a represent statistical significance at the 95% confidence level around the means of each region. Because there were only two Spanish wines, they are represented by a single line connecting them. It is important to note that the Marlborough mean and ellipse shows no overlap with the international wines, but does show some similarities with the Wairarapa wines (Figure 3.1a).

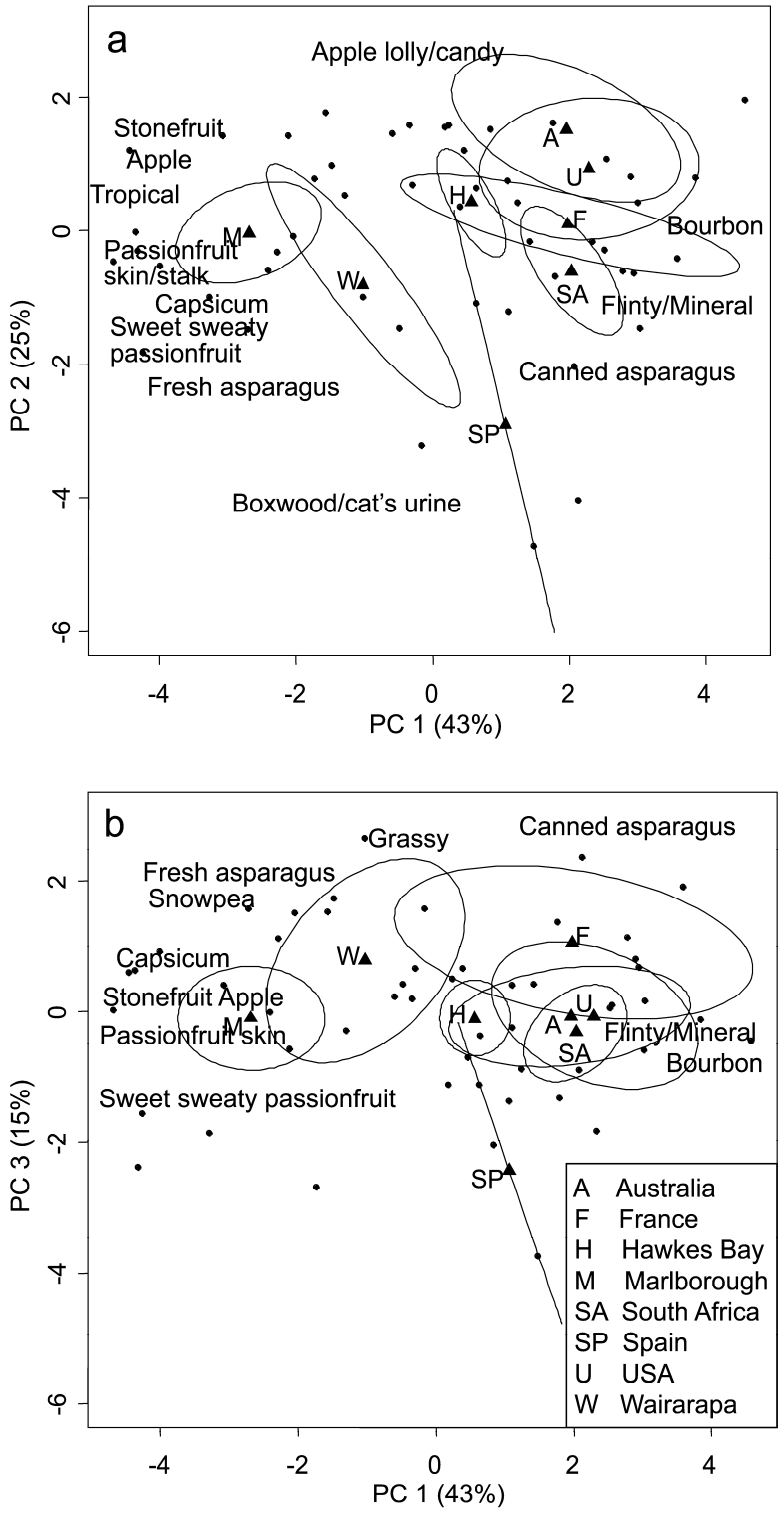

Figure 3.1a & 3.1b. Principal component analysis of sensory data of Sauvignon blanc wines from six countries. (3.1a) PC1 v. PC2. (3.1b) PC1 v. PC3. Means are represented by the countries' corresponding letters and ellipses represent 95% confidence limits surrounding the means.

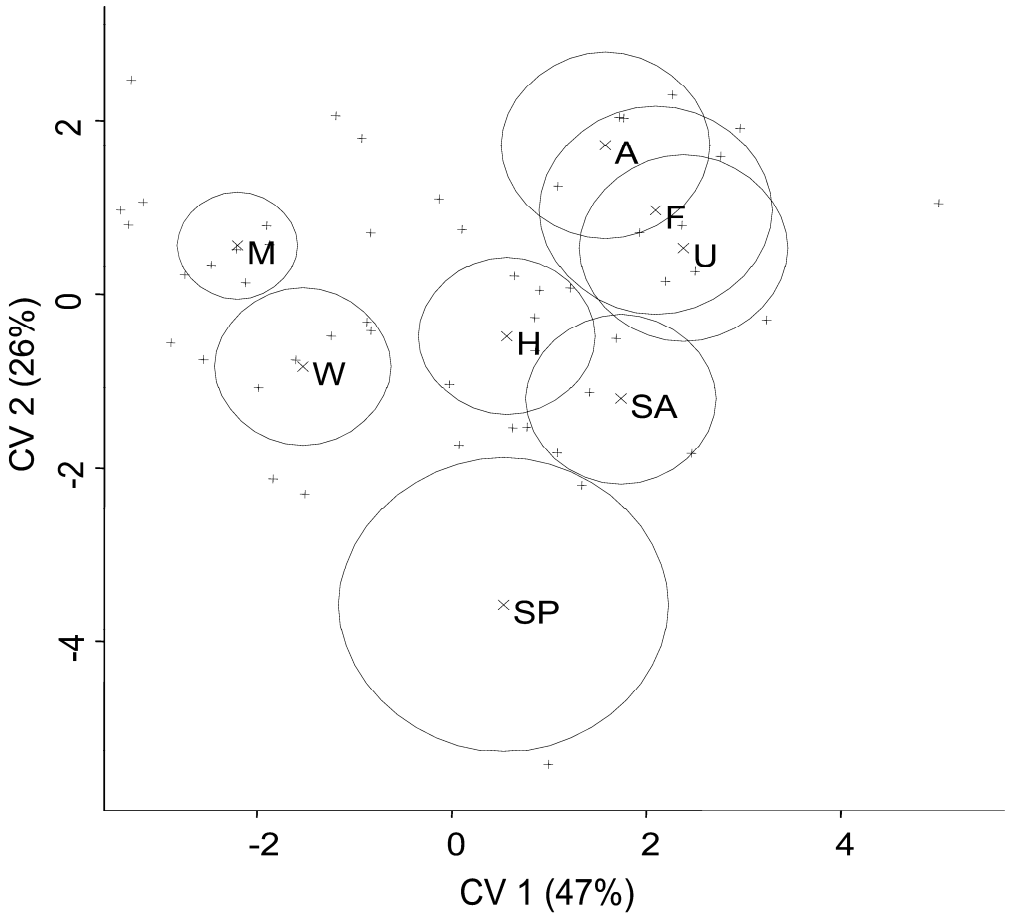

Figure 3.2. Canonical variate analysis (CVA) of sensory data of Sauvignon blanc wines from six countries [Australia (A), France (F), Hawke's Bay (H), Marlborough (M), South Africa (SA), Spain (SP) USA (U) and Wairarapa (W)]. Means are represented by the corresponding letters for each country and ellipses represent 95% confidence limits surrounding the means.

In the CVA graph, each wine region is represented by a circle, which indicates a 95% confidence interval around the mean score (Figure 3.2). The figure shows that the Marlborough region produces Sauvignon blanc wines that are significantly different ($P \leq 0.05$) from the wines from Hawke's Bay, Wairarapa, South Africa, France, Australia, the USA and Spain. These data suggest that New Zealand wines of the 2004 vintage had flavour profiles that were distinctive from those of the international wines. In the CVA graph, the sensory attributes on the left side of the x axis (CVA 1)

are apple, stonefruit, tropical, passionfruit skin/stalk, fresh asparagus, capsicum, sweet sweaty passionfruit, and cat's urine/boxwood. The right side of CVA 1 is represented by bourbon and flinty. These are similar attributes to those expressed in PCA 1 (Figure 3.1a and 3.1b). In PCA (Figure 3.1a), ellipses of the data from the Wairarapa and Marlborough regions overlap, but this is not the case for the means in CVA (Figure 3.2). These results occur because the PCA describes the similarities among the individual wines, whereas the CVA assesses differences between the regional means.

3.3.2 Aroma chemical analysis

Chemical analysis was conducted on 50 of the wines in this study (excluding the Spanish wines and one Hawke's Bay wine and including a fifth French wine). The chemical data for the four compounds shown in Table 3.4 show the Marlborough region wines as being significantly higher in 3MHA (sweet sweaty passionfruit) and 3MH (passionfruit skin/stalk) than wines from all other regions. The Wairarapa wines were also high in 3MH, and had even higher amounts of MIBP (capsicum) than wines from other regions. The similarity of asparagus and MIBP 'green notes' may explain the separation of Wairarapa wines seen in Figure 3.2. There were no differences found in the amounts of the MIPP (snowpea) attribute among the wines from the different regions. Table 3.4 highlights the variation of chemical concentration within the Marlborough region. Thus, although mean concentrations of 3MHA appear high for Marlborough, the variation in concentration values of 3MHA within the Marlborough wines was also large, allowing for the possibility that specific wines within the region may indeed have had lower concentration levels of 3MHA than wines from other regions.

Table 3.4. Levels of MIBP, MIPP, 3MHA and 3MH in Sauvignon blanc wines (n=50) sampled from different regions.

MIBP (ng/L)	Hawke's Bay	Waira-rapa	Marl-borough	Australia	South Africa	France	USA
Mean*	**14.2ab**	**34.8b**	**22.0b**	**14.5ab**	**7.1a**	**7.9a**	**4.1a**
Min.	8.9	25.6	12.6	10.1	3.5	4.8	< 2.2
Max.	22.9	47.2	30.6	19.2	12.1	11.8	5.7
Std Dev	6.1	8.9	5.9	3.9	4.0	3.6	1.7

MIPP (ng/L)	Hawke's Bay	Waira-rapa	Marl-borough	Australia	South Africa	France	USA
Mean*	**7.8a**	**9.5a**	**8.4a**	**11.9a**	**7.9a**	**8.1a**	**7.8a**
Min.	7.0	8.1	6.3	10.8	6.3	6.0	7.4
Max.	8.3	11.2	11.4	13.7	9.1	9.7	8.2
Std Dev	0.85	1.2	1.3	1.2	1.1	1.9	0.58

3MHA (ng/L)	Hawke's Bay	Waira-rapa	Marl-borough	Australia	South Africa	France	USA
Mean*	**66.0a**	**83.7a**	**485.8b**	**72.4a**	**50.0a**	**28.6a**	**45.1a**
Min.	22.0	28.0	40.5	64.3	10.1	0.0	19.8
Max.	124.6	212.1	2507.0	78.1	119.2	83.4	62.6
Std Dev	45.0	60.0	583.7	5.7	41.1	34.2	18.1

3MH (ng/L)	Hawke's Bay	Waira-rapa	Marl-borough	Australia	South Africa	France	USA
Mean*	**1733.1a**	**4210.0b**	**6604.1c**	**2379.4ab**	**1722.3a**	**2049.7ab**	**2094.4ab**
Min.	925.0	1600.4	1477.6	1051.0	1013.0	687.7	860.2
Max.	3088.4	8733.3	18681.3	5241.0	2955.0	3053.8	4492.4
Std Dev	765.0	2474.3	5285.2	1664.4	700.9	869.5	1628.4

*Means in the same row with different letters are significantly different ($P \leq 0.05$).

3.3.3 Relationship between chemical and sensory data

Table 3.5 shows the correlations (r^2 >0.50) for each of three chemical flavour compounds (3MHA, 3MH, MIBP) with their respective sensory attributes. The concentration of these thiols can be used to predict the tropical characteristic of wine. The thiols (3MHA and 3MH) had the highest values for the coefficient of determinations (tropical, sweet sweaty passionfruit, passionfruit skin/stalky, stonefruit). The tropical reference standard was highly correlated with two chemical compounds 3MHA (r^2=0.80) and 3MH (r^2=0.65). The sweet sweaty passionfruit attribute maintained a relatively high correlation (r^2=0.73) with 3MHA, which was the sensory reference standard for this attribute (Table 3.2). These results support using the chemical measurement of 3MHA to predict the sensory perception of tropical and sweet sweaty passionfruit characteristics. The flavour compound 3MH showed a stronger relationship with the passionfruit skin/stalky attribute (r^2=0.63), which is the reference standard for this attribute (Table 3.2). Measurement of the concentration of 3MH would predict the sensory perception of passionfruit skin/stalk but not as strongly as using the concentration of 3MHA to predict sweet sweaty passionfruit characteristic in the wine.

The green compound MIBP had the highest positive correlation with the fresh asparagus attribute at r^2=0.57 and the highest negative correlation with the bourbon attribute (r^2= -0.54). Wines perceived as higher in capsicum, like those from the Marlborough region, were lower in the bourbon sensory attribute. The reverse was also true with French wines being higher in bourbon and lower in the capsicum sensory attributes. Regional wines that were high in bourbon did not necessarily possess a high alcohol content. For example, wines from Australia had the lowest mean alcohol at 10.6% ethanol, but still were perceived as having a relatively high bourbon characteristic. Bourbon was described by the panellists as being more of the earthy, smoky character of bourbon rather than the alcoholic character of bourbon.

The green compound MIBP had an even higher correlation with the fresh asparagus attribute (r^2=0.57) than with the capsicum attribute (r^2=0.37). Though 0.57 is not high correlation it does indicate some association with a green character. Wines having higher MIBP concentration will exhibit more fresh asparagus notes. The capsicum character was probably masked by the other components in the wine.

Table 3.5 confirms the results of Tominaga and co-workers (Tominaga et al. 2000,

Table 3.5. Coefficient of determinations of 3MHA, 3MH and MIBP and sensory attributes of Sauvignon blanc wines. Sensory attributes selected had higher than 0.50 in absolute values of coefficient of determination for the specific chemical (n=50).

Descriptor	Coefficient of determinations*
3MHA	
Tropical	0.80
Sweet Sweaty Passionfruit	0.73
Passionfruit skin/stalk	0.72
Stonefruit	0.57
3MH	
Passionfruit skin/stalk	0.63
Sweet Sweaty Passionfruit	0.55
MIBP	
Fresh Asparagus	0.57
Bourbon	-0.54
Sweet Sweaty Passionfruit	0.53

* Coefficient of determinations *P*-value $\leq$0.01.

Tominaga et al. 1998a, Tominaga et al. 1998b), who described the thiols as passionfruit descriptors, and Lacey and Allen, who described MIBP as green (Allen and Lacey 1999). The thiols (3MHA and 3MH) were highly correlated with their associated sensory attributes. These two thiols would serve as better predictors in modelling the sensory profile of wine than MIBP, which has a lower correlation with its sensory attribute, capsicum.

Figure 3.3 depicts the PLSR plot which investigates the relationship between the chemical analyses and the trained panel data. The two thiols were shown in close

proximity to the sensory attributes of tropical, passionfruit skin/stalk, and cat's urine/boxwood, which are terms that have been used to describe these thiols previously suggested by Tominaga and co-workers (2000, 1998a), Dubourdieu (2006) and Lund et al. (2006). Boxwood has been used to describe high concentrations of 3MHA (Bouchilloux et al., 1998). The reason explaining the thiols close proximity to cat's urine/ boxwood could be that 4-mercapto-4-methylpentan-2-one (4MMP) is in the same thiol chemical family. Aznar et al. (2003) found that their predictive model of Spanish red wines was strengthened by grouping chemical families on the basis of their sensory and chemical analyses.

The current study confirms and supports these earlier studies with additional correlation of sensory attributes with chemical composition data.

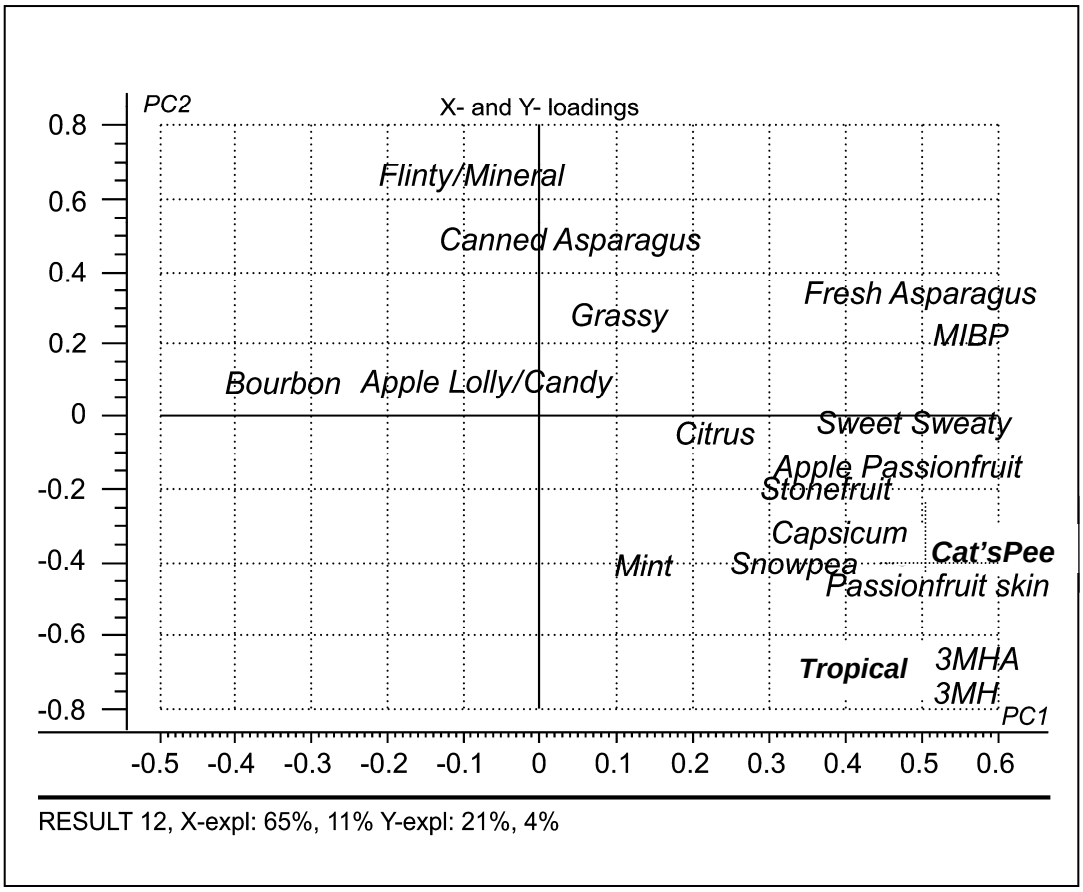

Figure 3.3. Partial least square regression of sensory attributes and chemical flavour compounds of Sauvignon blanc wines.

3.3.4 Consumers

Of the 109 consumers, 100% were wine consumers. The author wishes to point out that the percentage of women (69%) was higher than the New Zealand percentage of women wine drinkers (55%) (Bruwer, 2007). Most of the participants in this study were New Zealanders (69%). The other nationalities were Asian, Pacific Islander, European, Sri Lankan, Australian, Indian and American, none comprising more than 15% (Table 3.6). When asked about their white wine preferences and habits the largest percentage of consumers in this study indicated they preferred and regularly drank Sauvignon blanc (Table 3.6). The second most preferred white wine was Chardonnay. Forty-one percent of the consumers in this study primarily drank white wine, while 20% drank predominately red wine and 39% expressing no preference between red or white wine. When these consumers were asked to list the wines they normally drank, 82% of these consumers normally drank Sauvignon blanc, and 64% drinking Chardonnay and 48% drinking Riesling. These consumers (86%) normally spent NZ$10-20 (US$7 -15) on a bottle of wine (Table 3.6).

After completing the demographic information and choice questionnaire, the consumers tasted the wines and rated their preference for each wine. The means and ANOVA of their preferences showed these consumers significantly preferred two of the Marlborough wines compared to wines from Hawke's Bay, Australia, South Africa, France and Wairarapa (Table 3.7). The two wines from Marlborough had highest intensities of stonefruit, sweet sweaty passionfruit, cat's urine, passionfruit skin/stalk, and tropical, as well as being lowest in bourbon and flinty. The least preferred wine (Wairarapa) possessed average intensities for all the attributes. The French and the South African wines were high in mineral/flinty and bourbon characteristics. The Australian wine was highest in apple lolly and lowest in sweet sweaty passionfruit, capsicum, cat's urine, passionfruit skin, and fresh asparagus characteristics. The Hawke's Bay wine was highest in bourbon and mineral/flinty but lowest in tropical, citrus, stonefruit and apple characteristics. An external preference map illustrates the sensory space of the wines in relationship to the consumer preference data, and a hierarchal cluster analysis identifies groups of consumers and their preferences in relationship to the sensory data (Jaeger et al., 2003b; Jaeger et al., 2003a). The dendrogram from the cluster analysis identified two distinct groups of consumers.

Table 3.6. Demographic information from the New Zealand wine consumers (n=109).

Demographic	Percent	Demographic	Percent
Gender		**Wine preference**	
Female	69%	White	41%
Male	31%	Red	20%
Age		Both	39%
18-24 years	10%	Neither	0%
25-34 years	40%	**White wine preferences**	
35-44 years	23%	Sauvignon blanc	39%
45-54 years	18%	Chardonnay	26%
> 55 years	9%	Riesling	12%
Status		Sparkling	8%
Single	22%	Gewurztraminer	6%
In a relationship	9%	Pinot gris	6%
Couple living together	28%	White wine blend	1%
Married	34%	Other	0%
Divorced	3%	I do not like white wine	2%
Separated	2%	**White wine normally consumed***	
Widowed	2%	Sauvignon blanc	82%
Wine consumption		Chardonnay	64%
Once a day	13%	Riesling	48%
3-4 times a week	44%	Sparkling	38%
Once a week	28%	Gewurztraminer	24%
Twice a month	10%	Pinot gris	39%
Once a month	5%	White wine blend	3%
Once a year	0%	Other	3%
Never	0%	I do not like white wine	3%
Main household shopper		**Average price spent on a bottle of wine**	
Yes	72%	< NZ$10	6%
No	28%	NZ$10 to NZ$14	43%
Income		NZ$15 to NZ$20	43%
<NZ$25,000	5%	NZ$21 to NZ$30	7%
NZ$25,001 to NZ$50,000	22%	NZ$31 to NZ$40	1%
NZ$50,001 to NZ$75,000	18%	**Ethnicity**	
NZ$75,001 to NZ$100,000	18%	New Zealand	70%
NZ$100,001 to NZ$150,000	28%	Asian	14%
>NZ$150,000	8%	European	6%
Do not wish to answer	1%	Australian	2%
		Pacific Island	1%
		Other	6%
		Do not wish to answer	1%

*Consumer were asked to check as many as applied.

Table 3.7. Single factor analysis of variance of New Zealand consumers' overall liking scores (n=109) for eight Sauvignon blanc wines ($P \leq 0.05$). Fisher's Least Squared Differences were based on 95% confidence levels.

Wine Region	Mean overall liking score
Wairarapa	55.8a
France	62.4ab
South Africa	63. 3ab
Australia	63.5ab
Hawke's Bay	64.0ab
Marlborough 2	69.3bc
Marlborough 4	74.7c
Marlborough 7	75.7c

***** Means in the same column with different letters are significantly different (LSD = 7.57, *P*-value≤0.05

Cluster 1 showed a consumer group that prefers a stonefruit, passionfruit skin/stalk, capsicum, sweet sweaty passionfruit, fresh asparagus, boxwood/cat's urine-style Sauvignon blanc; whereas the Cluster 2 consumers prefer their Sauvignon blanc with bourbon as well as flinty/mineral characteristics (Figure 3.4). Cluster 1 comprised the largest portion of consumers (77%) surveyed in this research. Cluster 1 contained a larger percentage (53%) of respondents in the younger age brackets (<34 years) compared with Cluster 2. Cluster 1 consumers were more likely to spend over $15 on a bottle of wine (54%) and to be New Zealanders (66%). Divorced people were primarily in Cluster 2 and women dominated this cluster (4 women to every 1 male). Eighty-four percent of Cluster 1 normally drank Sauvignon blanc as their primary white wine whereas there were only 68% in Cluster 2 who normally drank Sauvignon blanc. Cluster 1 contained a higher percentage of white wine-only drinkers (43%) or

those who drank both red and white wines (41%), compared with Cluster 2, which had over twice as many red wine-only drinkers (36%).

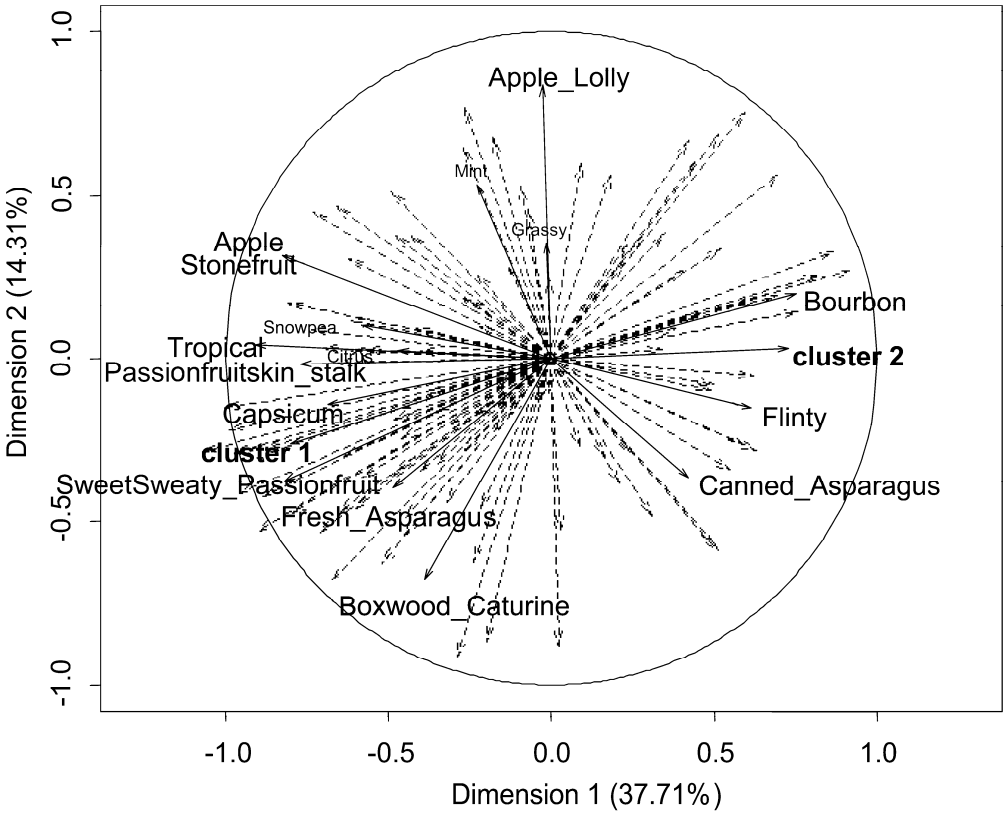

Figure 3.4. External preference map of New Zealand consumers (n=109) and the Sauvignon blanc wine (n=8) sensory attributes. Dotted lines represent each consumer. Solid lines represent the sensory attributes vectors.

3.4 Discussion

In past research the Sauvignon blanc flavour profile has been attributed to the methoxypyrazines (Allen and Lacey, 1999) which gives the wine green, capsicum characteristics. However, it has been noted that wines rarely have a sole "impact" compound, such as methoxypyrazine (Noble and Ebeler, 2002). Using sensory, chemical, and consumer analyses, the current research scientifically determined that the 2004 Marlborough Sauvignon blanc possessed a distinctive and predictable flavour profile that New Zealand consumers rated as most preferable.

The past literature has enumerated the many attributes associated with Sauvignon blanc wine (Allen et al., 1991; Lacey et al., 1991; Allen and Lacey, 1999; Tominaga

et al., 2000; Murat et al., 2001; Dubourdieu et al., 2006; Tominaga et al., 2006). These attributes (capsicum, grassy, passionfruit skin/stalk, sweet sweaty passionfruit, cat's urine/boxwood) are characteristics that were also evident with thewines evaluated in this study. The strongest sensory attributes in Marlborough wines of this study were the high intensities of the fruity and green characteristics, such as tropical, sweet sweaty passionfruit, apple, stonefruit, capsicum, passionfruit skin/stalk, and fresh asparagus. The sensory attributes noted in the wines were highly correlated with the chemical measurements of thiol concentrations. Sensory attributes that contributed less strongly to the Marlborough style were mint, grassy, citrus and snow pea. The sensory evaluation of snow pea intensities in the wines were confirmed by the chemical measurements of MIPP concentrations. Both analyses showed no significant differences among the wines in this study.

In the sensory portion of this research, the 2004 Marlborough Sauvignon blanc wines not only had green characteristics (capsicum, passionfruit skin/stalk, and fresh asparagus), but also high fruity characteristics (tropical, sweet sweaty passionfruit, apple, stonefruit). Statistical analysis of the sensory data (PCA and CVA) demonstrated that the 2004 New Zealand Sauvignon blanc had a distinctive flavour profile which was significantly different from the flavour profiles of the wines from France, Australia, South Africa, the United States (USA) and Spain. Although the French, USA and South African wines were quite similar, Australian wines were distinguished by their apple lolly/candy characteristic.

The French, South African, Australian and USA Sauvignon blanc wines contained more mineral, flinty, and bourbon sensory characteristics. Analysing the flavour compounds found in these international flavour profiles, such as 4-mercaptomethyl pentane for the cat's pee/boxwood and benzyl methyl thiol for flinty/mineral overtones, as reported by Tominaga et al (1998b, 2000), could assist in creating an improved chemically-based predictive model.

The chemical concentration of 3MHA and 3MH had higher means in Marlborough wines compared with those from the other regions. These high concentrations showed a strong correlation with tropical sensory attributes. 3MHA had high correlation with the sweet sweaty passionfruit, and 3MH was correlated with passionfruit skin/stalk.

Capsicum is a characteristic commonly used to describe Sauvignon blanc, yet within this study, MIBP had greater correlation with fresh asparagus than with capsicum.

Further investigation might determine what other components could be masking the capsicum attributes in Marlborough Sauvignon blanc.

The sensory data from the 2004 vintage established that Marlborough and Wairarapa wines were somewhat similar, although the latter exhibited stronger asparagus notes. Similar to the results of the 2003 wines, the 2004 vintage from Hawke's Bay had the lowest concentrations of 3MHA, 3MH and MIBP compared with the other two regions (Lund et al. 2005). The 2005 vintage has been examined to determine if there is continued consistency among the three vintages.

The Marlborough wines in this study had the highest levels of titratable acidity and residual sugar, the latter only significantly higher than wines from France and Spain. Interestingly, mean titratable acidity levels were significantly higher in all the New Zealand wines compared with the international wines. Increasing acidity is known to diminish perception of fruit characteristics, such as banana, in kiwifruit pulp (Marsh et al., 2006), and when sugar was added, the perception of fruit characteristics increased. Research predicted that an increase in sugar concentration would increased the headspace concentration of "fruity" volatiles in kiwifruit pulp, such as ethyl butynoate and (*E)*- 2- hexanal (Friel et al., 2000). It might be valuable to measure the headspace of Marlborough wines and compare the results to wines with lower levels of titratable acidity and residual sugar.

The chemical data in this research supported the statement that Marlborough Sauvignon blanc wines have a complex style that is not influenced by a single "impact" compound (Noble and Ebeler, 2002). There were higher concentrations of thiol (3MHA and 3MH) and methoxypyrazine (MIBP), which created some of the fruity and green characteristics.

The methoxypyrazine of Marlborough Sauvignon blanc has more of a fresh asparagus sensory attribute than a capsicum sensory attribute. Both the 3MHA and the MIBP were more closely associated with a natural product standard (tropical and asparagus, respectively) than with a single chemical compound as a reference standard (sweet sweaty passionfruit and capsicum, respectively). The natural product reference standards may more successfully convey a complex sensory perception to a panellist. Perhaps a study evaluating the comparison of sensory reference standards comprised of solely chemical compounds versus reference standards comprised of solely natural products would be of interest, in determining whether one set of standards indicates a better prediction of sensory attributes.

The low correlation between MIBP and capsicum character could be explained by a possible masking of MIBP by other components in the wine. Wine is a complex medium, in which many masking and synergistic interactions occur (Lawless, 1999; Peinado et al., 2004). For example, 12% ethanol in water has an extremely strong smell, whereas at the same concentration in wine, the odour is greatly masked by other volatile compounds. Conversely, ethanol is capable of masking the perception of esters (Escudero et al 2007). The negative correlation of the bourbon characteristic to the concentration of MIBP may suggest that there are sensory characteristics that are masked in the presence of compounds such as MIBP. Conversely, the capsicum characteristic may be explained by more than just the chemical concentration of MIBP. A study of sensory and chemical analyses of Spanish red wines found vegetal peppery characteristic to be correlated to isoacids, ethyl esters of isoacids, and fusel alcohol (Aznar et al., 2003). More chemicals will need to be measured and correlated with the sensory attributes to better understand the capsicum perception and the effect MIBP has on the perception of wine aroma.

The thiol and MIBP concentrations could be used to predict a Marlborough style, but it is apparent there are other sensory attributes contributing to the Marlborough flavour profile that will need to be considered. Esters such as ethyl decanoate and ethyl hexanoate, are also known to be present in Sauvignon blanc wines (Benkwitz et al., 2007). Other flavour compounds, such as esters and C6 compounds, should be measured since they contribute to the fruity and green characteristics in wines. Such investigations would enable a more predictive model to be used in anticipating sensory attributes. Studies evaluating synergistic and masking effects of a wider range of chemical compounds would also be beneficial to understanding the complex attributes found in wine.

Although there were differences between the wines that could be measured through chemical analyses and sensory evaluation, from a commercial point of view, the ultimate consideration is whether the average wine consumer could perceive a difference. Price is less of a dominant predictor of purchasing behaviour as wine consumers are becoming more interested in other aspects of wine. Regional reputations are beginning to play a bigger role for the “highly product involved,” more knowledgeable wine consumer (Tustin and Lockshin, 2001; Schamel, 2006; Hollebeek et al., 2007). Consumers in this study preferred wines that presented sweet sweaty passionfruit, capsicum, passionfruit skin/stalk, and fresh asparagus overtones. These results would suggest the New Zealand consumers could

recognise and prefer the Marlborough Sauvignon blanc style. One Spanish study found local wines were preferred by locals and purchased on that basis (Martinez-Carrasco et al., 2005). Another Spanish consumer study by Sanchez and Gil (1997) discovered that wine origin was more important than price and vintage in influencing consumer selection. The authors found that while rural consumers desired local wines, urban consumers preferred the perceived higher prestige of wines from the Rioja region, indicating that effects of regionality on consumer behaviour are broader than consideration of a wine's sensory characteristics.

New Zealand wine consumer significantly preferred the unique sensory attributes found in Marlborough Sauvignon blanc wine. These consumers were familiar with Sauvignon blanc, as evident in the cluster analysis results identifying the frequency and selection preferences of their purchasing behaviour. The majority of the consumers in Cluster 1 chose Sauvignon blanc as their most purchased and preferred white wine. In contrast, Cluster 2 preferred the flinty, mineral profile of the international wines. Interestingly, Cluster 2 had a greater percentage (44%) of non New Zealanders while Cluster 1 was only 23%. The research design did not include any determination of how long the non New Zealander panellists had been residing in New Zealand, or the extent of their wine consumption behaviours prior to their arrival. Without this knowledge, only limited conjecture can be made as to whether a partial familiarity with Marlborough Sauvignon blanc may be influencing their wine preference choices. Cluster 2, with more non New Zealanders, consumed less wine compared to New Zealanders. Sixty-five percent of New Zealanders in the current study consumed wine 3 or more times per week, whereas only 33 % of non New Zealanders were consuming wine that frequently. Higher wine consumption might infer that these consumers have a greater familiarity with Marlborough Sauvignon blanc and therefore a stronger preference as in the Spanish study (Martinez-Carrasco et al., 2005).

According to one study, Australian and New Zealand consumers are increasingly preferring cool climate wines such as Sauvignon blanc (Schamel and Anderson, 2003). Other export markets may not show the same trend in wine preferences. Determining whether international consumers share this cool climate wine preference will be important to the New Zealand wine export industry.

3.5 Conclusion

Results from sensory analysis, chemical analysis and New Zealand consumer preference data substantiate the claim that when consumers receive a Marlborough Sauvignon blanc wine, it exhibits distinctive flavours.

The 2004 vintage showed significant differences between Marlborough New Zealand to the international Sauvignon blanc wines tested in this study. More international wines should be analysed and tested to confirm these results. Regional differences were also apparent within New Zealand, especially between Hawke's Bay and Marlborough wines. Wairarapa wines, although similar to those from Marlborough, contained more green characteristics, and consumer data suggested a preference for Marlborough wines. The chemical analysis data showed strong correlations of three chemicals (3MHA, 3MH, MIBP) with some of the sensory attributes. In comparison to methoxypyrazine, the thiols showed higher correlations with the sensory attributes. Investigating the effects of flavour compound masking/synergism may contribute to a more authentic representation of the Sauvignon blanc flavour profile. Lastly, consumers within New Zealand preferred Marlborough Sauvignon blanc to the international Sauvignon Blanc wines tested in this study.

CHAPTER 4

EFFECTS OF POLYPHENOLS ON THE PERCEPTION OF KEY AROMA COMPOUNDS FROM SAUVIGNON BLANC WINE[3]

4.1 Introduction

4.1.1 Sauvignon blanc key odour compounds

In Chapter 3 the key odour compounds contributing to the distinctive flavour profile of in New Zealand Sauvignon blanc were shown to include methoxypyrazines (e.g. MIBP) and thiols (e.g. 3MH and 3MHA). Of the regions tested, Marlborough wines had the highest concentration of thiols (3MHA and 3MH), and Marlborough and Wairarapa regions had wines with higher concentrations of MIBP (Table 3.4). Allen et al. (1991) determined that MIBP had a low detection/perception threshold, and with concentrations that were 10 to 20 times higher than this low threshold, he concluded that MIBP was a critical contributor to the green flavours of Sauvignon blanc wines.

Tominaga et al. (Tominaga et al., 2000) found that 3MHA had a lower sensory perception threshold concentration than 3MH, in both water and wine media. Based on the high concentration of 3MHA in Marlborough Sauvignon blanc, his finding suggested that 3MHA contributed a stronger sensory impact on New Zealand Sauvignon blanc wine than 3MH. It is interesting to note that significantly higher quantities of both 3MHA and 3MH compounds have been found in the Sauvignon blanc wines of New Zealand's Marlborough region, in comparison to the Sauvignon blanc wines from either New Zealand's other wine regions or the Sauvignon blanc wines from other countries (Table 3.4). The thiol compound 3MH contributes an herbaceous odour characteristic in Sauvignon blanc wine described by the sensory panel as passionfruit skin/stalk (Table 3.2). 3MHA contributes the odour characteristic described by the sensory panel as esters are also major contributors to

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the odour characteristics of New Zealand Sauvignon blanc wine (Benkwitz et al., 2007). A sensory panel described ester characteristics banana lolly (amyl acetate), herb floral (ethyl octanoate) and honey mead (ethyl decanoate) (Lund et al., 2007).

4.1.2 Sauvignon blanc polyphenols

As with many white wines, Sauvignon blanc primarily contains three types of polyphenols, the flavan-3-ols, hydroxycinnamic acids (as tartrate esters in grapes) and flavonols (glycoside forms in grapes), which can be represented by the common monomeric compounds catechin, caffeic acid and quercetin, respectively. The concentration of these compounds in Sauvignon blanc wines can reach 10 mg/L for catechin (and epicatechin), 100 mg/L for caffeic acid and related hydroxycinnamic acids, and 10 mg/L for quercetin and its glycosides (Frankel et al. 1995, Maggu et al. 2007).

There has been very little sensory research examining the role of white wine polyphenolic compounds on the perception of wine odour. Most of the sensory research of wine polyphenolic compounds has focused on the perception of mouth-feel and taste. For instance, a number of studies have assessed sensory measurements of astringency and/or bitterness in red wine polyphenols. (Robichaud and Noble 1990, Lawless et al. 1994, Gawel et al. 2000, 2001, 2007, Francis et al. 2002, Monteleone et al. 2004, Tao et al. 2007). A large molecule such as a polyphenol is too massive to be perceived by the olfactory system. Molecules with molecular weights over 300 to 400 Daltons do not have the capacity to reach the olfactory receptors in the human nose (Jacob 2002).

The research that has been conducted on red wine polyphenols in relation to odour compounds is limited to chemical measurements of aromatic esters rather than the sensory perception of the odour compounds (Dufour and Sauvaitre 2000). Only one research project has evaluated the sensory effects of polyphenols (gallic acid and naringin) on the intensity of perception of odour compounds (2-methylpyrazine and ethyl benzoate) in water and wine matrices (Aronson and Ebeler 2004). In that study, the two polyphenols were found to suppress both of the odour compounds when combined singularly in water matrices. However, when the polyphenols and odour compounds were combined in the wine matrices (Chardonnay and Cabernet Sauvignon), the sensory analyses were not statistically significant, even though chemical headspace analysis determined a significant reduction in the concentration of odour compounds. The authors attributed these inconclusive sensory results to

insufficient panellist training and there being an existing presence of tannins that might lend itself to no further measurable effects.

The current study was designed to continue investigating the effects of polyphenols on odour perception. Building on the foundation of Aronson and Ebeler's research, the current research increased the depth of sensory panel training before attempting any perception measurements.

4.1.3 Measurement of perception of Sauvignon blanc odour compounds

Because this study was aimed at determining whether well trained panellists could detect any perceivable differences in Sauvignon blanc odour compounds as a result of varying levels of polyphenols, a difference test was identified as the appropriate method (Lawless and Heymann 1999). The *R*-Index methodology has commonly been used in sensory and consumer research to measure product variation (O'Mahony and Rousseau 2003). The *R*-Index can be used to determine when a human can perceive a difference between two concentrations of a volatile compound. One sample would have no added amount of the volatile compound (which is referred to as the noise), while the other sample (the signal) would have an added amount. Bi and O'Mahony (1995) used this methodology to measure the difference between cookies made with two different concentrations of sugar. Their objective was to determine the lowest difference in sugar concentration at which a panellist could still perceive a difference from the original cookie formula. This *R*-Index methodology was used in this study.

The main research objective of this study was to investigate the sensorial odour effects that polyphenolic compounds induced on key odour compounds found in New Zealand Sauvignon blanc wine.

4.2 Materials and Methods

4.2.1 Sample preparation (All chemical analyses were conducted by Laura Nicolau's Wine Science Chemistry team).

A non-Sauvignon blanc white wine (N.V. Chasseur dry white table wine) was used for the experiment. This wine was diluted by 50% with Microlene^{TM} filtered water and was referred as the 'diluted base wine'. The justifications for diluting the wine are

explained below. The base wine had a pH of 3.20 (± 0.10), 6.25 (± 0.35) % ethanol (v/v), 4.0 (± 1.0) g/L residual sugar and 3.25 (± 0.15) g/L titratable acidity.

The diluted base wine was chemically analysed for the methoxypyrazine and thiols using a procedure reported in Section 3.2.6 and 3.2.7, respectively. The diluted base wine was found to have 538 (±28) ng/L of 3MH. MIBP, 3MHA and ethyl decanoate were not detected in the diluted base wine. The detection limits of the analytical methods, calculated using International Union of Pure and Applied Chemistry (IUPAC) methodology were 1 ng/L for MIBP, 25 ng/L for 3MH and 8 ng/L for 3MHA (Currie 1995).

The quantification of the ester, ethyl decanoate, was as follows. A triple extraction (4:2:2 mL) with 1:1 diethylether:hexane was undertaken on 50 mL of sample spiked with 25 µL of octan-3-ol (920 mg/L, in absolute ethanol) as internal standard. The organic phase was dried using anhydrous sodium sulfate and concentrated down to 100 µL under nitrogen flow. Two µL were analysed by gas chromatography (Agilent 6890N) using a capillary column, HP-Innowax (60 m x 0.252 mm x 0.25 µm). The splitless injection port was heated to 230ºC and the split vent was opened after 1 min. The carrier gas was helium and the pressure was 109 kPa. The initial oven temperature was 40ºC (for 10 minutes) then ramped at 6ºC/min to 170ºC, further raised to 240ºC and held for 10 minutes. The GC was coupled to an Agilent 5973 mass-selective detector. The interface temperature was kept at 230ºC and the ion source was working in electron ion (EI) mode at 70 eV. The quadrupole temperature was set at 150ºC. The analysis was performed in single ion molecule (SIM) mode. The ions 70, 88, 101 m/z were selected for ethyl decanoate (70 m/z was used for quantification) and the ions 59, 83 101 m/z were selected for the internal standard (59 m/z was used for quantification). The standard curve was prepared by adding increasing quantities of ethyl decanoate to a wine to obtain six different concentrations, from 50 to 300 µg/L. The regression equation obtained was $y = 2.8318x - 0.0533$ with $r^2 = 0.99$. An average relative standard deviation of 12.2% was obtained during a survey of 50 Sauvignon Blanc wines analysed in triplicate.

The concentration of polyphenols (n = 3) in the diluted base wine were determined at 1.84 (± 0.17) mg/L for catechin, and 2.30 (± 0.08) mg/L for caffeic acid, while no quercetin was detected, using a reverse phase HPLC method reported elsewhere (Brajkovich et al. 2005, Tao et al. 2007). The concentrations of the polyphenols in the diluted base wine were increased by 10 mg/L (catechin and quercetin) or 100

mg/L (caffeic acid) such that the values listed in Table 4.1 to 4.4 are the sum of the added and naturally occurring polyphenols.

Polyphenols, catechin (Sigma), caffeic acid (Sigma), and quercetin (Sigma) were weighed on an analytical balance and dissolved in ethanol (99% purity, Sigma). One mL polyphenol mixture at the appropriate concentration was added to a litre of diluted base wine.

Standard stock solutions of the methoxypyrazine and thiols were prepared. MIBP (Acros Organics) and 3MH (Interchim), 3MHA (Oxford Chemical) were diluted to the following concentration for stock solutions MIBP = 245 μg/μL, 3MHA = 344 ng/μL, 3MH = 226.5 ng/μL with ethanol (Sigma). These stock solutions (1-30 μL) were diluted to the appropriate concentration on the day of testing and added to a litre of diluted base wine with the appropriate polyphenol. Stock solutions were protected from the light and stored at -20 ºC until the day of assessment. MIBP was wrapped in foil to protect from light degradation. Ethyl decanoate (Aldrich) was added directly to a litre of diluted base wine to the appropriate concentration listed in Table 4.4.

4.2.2 Trained panellists

Fifteen trained panellists experienced in tasting Sauvignon blanc were used to evaluate the polyphenols and key Sauvignon blanc flavour compounds. The panel ages ranged from 25 to 53 y. Panellists were pre-screened to make certain they were not anosmic to the compounds. Panellist pre-screening and two years of training with these compounds ensured that the panellists were sensitive to these compounds. The assessments occurred in booths following conditions as listed in Section 1.2.3. Assessments were conducted between 11 am and 12 pm, four days a week to alleviate any hunger or biorhythm effects. The samples were served in standard XL wine glasses with watch glass lids with 10 mL of sample aliquotted into each wine glass. Samples were prepared one hour prior to being served at room temperature (20°C). Panellists evaluated the samples orthonasally in a specified, randomised order (Section 4.2.3). Panellists were instructed to smell water between sample pairs. They were given a five minute break after evaluating a set of four paired samples, with a maximum of twelve paired samples evaluated at each session. Difference testing data was collected on a paper ballot.

4.2.3 Difference testing and data analysis

The difference test employed to measure the impact of polyphenols on sensory perception was the *R*-Index methodology outlined in Appendix C. An example of the evaluation form used is in Appendix E. The lowest concentrations at which the panellists could perceive a difference (sensory perception/detection threshold) were determined for these volatile compounds with no added polyphenols. Subsequently, these lowest concentration values were then compared to values obtained after the polyphenol compounds were added, to test for a resultant suppression or synergistic effect.

The coded pairs were presented in a balanced design, with each person receiving four paired samples in all combinations (AB, BA, BB, and AA). The noise sample ('A') contained the polyphenol being tested in a diluted base wine, and the signal sample ('B') contained the polyphenol being tested plus a predetermined amount of a volatile odour compound in a diluted base wine. The panellists were asked whether pairs were the 'same' or 'different' and whether they were 'sure' or 'unsure'. *R*-index (R_i) values were calculated and R_i – 50% results were compared with *R* critical value for a one-tailed test at a 2.5% significance level that the result is greater than the probability of chance. The critical value was found to be 19.1% for n=15 (or 0.691) using the table in Bi and O'Mahony (2007).

4.3 Results and Discussion

4.3.1 Perception of difference threshold

The lowest concentration at which the panel could perceive a significant difference for any increase in the concentration of the odour compound over naturally occurring amounts is shown (Table 4.1 to 4.4). At concentrations below these values the panel could not perceive a significant difference between the not supplemented diluted base wine (containing the indicated amounts of naturally occurring odour compound) and the supplemented diluted base wine. To ensure the validity of these base values, the results for the volatile thiols 3MH and 3MHA were retested with the panel 2 to 3 times over the span of a year.

These difference thresholds were closely related to the discrimination threshold, but differed in that they were dependent on the background matrix in which the tests

were undertaken – in this case the “diluted based wine” contained measurable levels of some of the odours (see below).

The effect of polyphenols was assessed for each odour compound by comparing the difference thresholds values obtained in the presence or absence of the added polyphenol. The effects of the polyphenol were then classed as “suppressing” or “accentuating”, depending on whether the difference thresholds value increased or decreased when the polyphenols were added.

While there was no measurable MIBP, 3MHA, or ethyl decanoate in the diluted base wine, there was 538 ng/L of 3MH present. Although it would be desirable to start with a complete absence of the odour compounds, it was considered to be more important to carry out the experiments within a realistic wine matrix. My previous research had demonstrated that single thiols in water were more difficult for panellists to consistently measure perception due to thiol high volatility. Attempts to use a model wine (ethanol, sugar, tartaric acid plus odour compounds) resulted in high levels of panellist fatigue from the ethanol. Ethanol has been demonstrated to mask volatile compounds, such as esters (Escudero et al. 2007). This masking should be considered when assessing perception. Future studies might include the assessment of compounds in water only to determine if the absence of ethanol affects the perception. Ferriera et al. (2007) recommended the use of a base wine medium for odour analysis to more closely simulate a real wine scenario. In the present research the panel evaluated samples having a base wine which had some ethanol and a pH similar to that which is normally measured for wine. These amendments attempted to simulate a solution matrix similar to the wines in which these volatile compounds would normally be perceived.

The catechin concentration mean and standard deviation in the samples was 11.9 $\pm$ 2.5 mg/L, while the caffeic acid samples were 92 $\pm$ 15 mg/L. The quercetin concentration was not detected even though an addition to 10 mg/L was made, indicating that the free quercetin had degraded over 2-3 hrs between making up the solutions and running the analysis by HPLC. The results shown by the addition of quercetin will need to be examined in a future study using a glycosidic quercetin derivative (e.g. rutin) to confirm that flavonols in wine are responsible for perception effects.

4.3.2 Polyphenol effects on MIBP

Table 1 shows that the perception of MIBP was suppressed by both catechin and caffeic acid, and somewhat by quercetin or its degradation products. A 'significant' result (*R*-Index value >0.691) for the perception of MIBP was achieved when 17 ng/L MIBP was added to the diluted base wine. At the concentrations used in this experiment, catechin and caffeic acid had a higher suppression ability than added quercetin by-products, which had no effect. However, when a total of either 12 mg/L of catechin or 102 mg/L of caffeic acid was present in the diluted base wine, the addition of MIBP to 175 ng/L was required before panellists perceived a difference. The average MIBP concentration found in New Zealand Sauvignon blanc in one survey was 23 ng/L with a range from 9 to 47 ng/L (Table 3.4). This represents a ten-fold increase in MIBP concentration compared with the panel's MIBP discrimination threshold and raises issues whether MIBP alone is responsible for a perceived capsicum odour. This observation would also explain data from Table 3.5, which showed a low coefficient of determination of 0.37 between the chemical concentration of MIBP in 50 Sauvignon blanc wines from around the world, and the sensory panel's perception of the green capsicum attribute, whose reference standard was MIBP. Such effects were also noted in a study by Marais et al (1998), in which it was found that the higher levels of MIBP in different South Africa regional wines did not necessarily correlate with the capsicum perception of these wines.

The mechanism by which the non volatile polyphenols suppress perception of MIBP is not known. One suggestion is that the large number of –OH groups on these polyphenols may form reasonably strong, although temporary, non-covalent bonds with the methoxypyrazine, thus lowering its volatility in the headspace above the wine. These non covalent bonds could involve interactions such as π-π, hydrophobic and hydrogen bonding (Dufour and Bayonove 1999, Jung et al. 2000). Conversely, the carbonyl group on the flavonol quercetin or quercetin degradation products may be less effective in interacting with MIBP than catechin.

Table 4.1. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of MIBP using *R*-Index difference testing (Bolded rows are the lowest concentrations of a perceivable difference.)

Polyphenol in both Noise & Signal	Poly-phenol Amount (mg/L)	MIBP in Noise* (ng/L)	MIBP in Signal** (ng/L)	Difference of Noise & Signal (ng/L)	*R*-Index***	Significantly Different
None	0	0	8.5	8.5	0.607	No
None	**0**	**0**	**17**	**17**	**0.860**	**Yes**[****]
Catechin	12	0	17	17	0.693	No
Catechin	12	0	34	34	0.417	No
Catechin	12	0	68	68	0.527	No
Catechin	12	0	80	80	0.544	No
Catechin	12	0	160	160	0.678	No
Catechin	**12**	**0**	**175**	**175**	**0.709**	**Yes**
Caffeic acid	102	0	17	17	0.607	No
Caffeic acid	102	0	34	34	0.633	No
Caffeic acid	102	0	68	68	0.664	No
Caffeic acid	102	0	80	80	0.489	No
Caffeic acid	102	0	160	160	0.567	No
Caffeic acid	**102**	**0**	**175**	**175**	**0.760**	**Yes**
Quercetin	**10**	**0**	**17**	**17**	**0.760**	**Yes**

*Noise (background) was defined as the diluted wine base with no MIBP added.
**Signal was defined as the diluted wine base with MIBP added.
*** *R*-Index critical =0.691 for N=15, unless otherwise stated ($P \leq 0.025$).
**** *R*-Index critical =0.696 for N=14, ($P \leq 0.025$).

4.3.3 Polyphenol effects on 3MH

The perception of the 3MH odour compound (described as “passionfruit skin/stalk”) was affected by the addition of polyphenols to different degrees. Before adding polyphenols, 3MH was perceived at 1750 ng/L but not at 1500 ng/L (Table 4.2), a result confirmed on three separate occasions. When 10 mg/L of catechin was added, the 3MH required an increase to 3000 ng/L before a difference was perceived. When 10 mg/L of quercetin was added, an even stronger suppression effect was observed, where the 3MH required an increase to 5000 ng/L before any difference was perceived. These increases in perception thresholds suggest that the odour compounds were interacting with the polyphenols.

Adding caffeic acid to the 3MH odour compound showed the opposite effect. 3MH was perceived at a lower concentration of 1500 ng/L, below the previously determined difference threshold value of 1750 ng/L. This result suggests that caffeic acid may have suppressed other odour compounds in the diluted base wine that initially masked the 3MH odour. Once the caffeic acid binds to these 3MH suppression compounds, the perception of 3MH becomes accentuated. In contrast to the accentuation effects from caffeic acid, the suppression effects of catechin and quercetin might play a more dominant role in the odour profile of Sauvignon blanc wine. The 3MH concentrations of New Zealand Sauvignon blanc have been found to vary between 900 and 18,000 ng/L, with a mean value of 5000 ng/L (Table 3.4). Since any observed suppressions of odour were occurring at levels well below the high 3MH concentrations found in New Zealand Sauvignon blanc, these suppression effects may be more important for the perceived odours of Sauvignon blanc wines from other countries, where 3MH concentrations have been measured at lower averages of approximately 2000 ng/L (Table 3.4).

Chemical concentrations can be used to predict sensory attributes. In a previous study correlating the sensory panel perceptions of 3MH to the chemical measurement of 3MH in 50 international Sauvignon blanc wines, the coefficient of determination was found to be 0.63 (Table 3.5). This would indicate that the 3MH in these wines was moderately perceivable.

Table 4.2. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of 3MH using *R*-Index difference testing**.** (Bolded rows are the lowest concentrations of a perceivable difference.)

Poly-phenol in both Noise & Signal	Poly-phenol Amount (mg/L)	3MH in Noise* (ng/L)	3MH in Signal** (ng/L)	Difference of Noise & Signal (ng/L)	*R*-Index***	Significantly Different
None	0	538	2038	1500	0. 597	No
None	**0**	**538**	**2288**	**1750**	**0. 806**	**Yes**
Catechin	12	538	2288	1750	0.560	No
Catechin	12	538	2538	2000	0.640	No
Catechin	**12**	**538**	**3538**	**3000**	**0.720**	**Yes**
Caffeic acid	102	538	1788	1250	0.530	No
Caffeic acid	**102**	**538**	**2038**	**1500**	**0.728**	**Yes**
Caffeic acid	102	538	2288	1750	0.960	Yes
Quercetin	10	538	2288	1750	0.518	No
Quercetin	10	538	2538	2000	0.493	No
Quercetin	10	538	3538	3000	0.682	No
Quercetin	**10**	**538**	**4538**	**5000**	**0.904**	**Yes**

*Noise (background) was defined as the diluted wine base with no 3MH added.
**Signal was defined as the diluted wine base with 3MH added.
*** *R*-Index critical =0.691 for N=15,unless otherwise stated ($P \leq 0.025$).

4.3.4 Polyphenol effects on 3MHA

With no additional polyphenols included in the diluted base wine**,** the panellists perceived added 3MHA at 200 ng/L, but not at 150 ng/L (Table 4.3), also confirmed on three separate occasions. When catechin was added to the diluted base wine, panellists could perceive 3MHA at 150 ng/L. 3MHA is a key flavour contributor to New Zealand Sauvignon blanc that was only slightly affected by the addition of three polyphenols.

My past research showed a high correlation between sensory attribute measurements and the corresponding 3MHA thiol concentration (Table 3.5), with a coefficient of determination of 0.73 between 3MHA concentrations and the sweet sweaty passionfruit sensory attribute (reference standard = 3MHA). The odour perception of 3MHA was also the least affected by added polyphenols, in comparison to the other odour compounds in the present study. The structure of 3MHA differs from 3MH in that the –OH has been esterified with acetic acid, and making the ester form less likely to interact with a polyphenol. The lack of suppression by the polyphenols and the higher concentration of 3MHA in New Zealand Sauvignon blanc wines demonstrate the crucial role 3MHA plays in the flavour of New Zealand Sauvignon blanc. Also important to note is that 3MHA has a perception threshold in water of 2 to 20 ng/L whilst 3MH is higher at 60 ng/L (Tominaga et al, 1998b).

Table 4.3. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of 3MHA using *R*-Index difference testing. (Bolded rows are the lowest concentrations of a perceivable difference.)

Polyphenol in both Noise & Signal	Poly-phenol Amount (mg/L)	3MHA in Noise* (ng/L)	3MHA in Signal** (ng/L)	Difference of Noise & Signal (ng/L)	*R*-Index***	Significantly Different
None	0	0	150	150	0.508	No ****
None	**0**	**0**	**200**	**200**	**0.742**	**Yes**
Catechin	12	0	75	75	0.471	No
Catechin	**12**	**0**	**150**	**150**	**0.707**	**Yes**
Catechin	12	0	200	200	0.793	Yes
Caffeic acid	102	0	150	150	0.636	No
Caffeic acid	**102**	**0**	**200**	**200**	**0.820**	**Yes**
Quercetin	10	0	150	150	0.587	No
Quercetin	**10**	**0**	**200**	**200**	**0.822**	**Yes**

*Noise (background) was defined as the diluted wine base with no 3MHA added.
**Signal was defined as the diluted wine base with 3MHA added.
*** *R*-Index critical =0.691 for N=15,unless otherwise stated ($P \leq 0.025$).
**** *R*-Index critical =0.696 for N=14, ($P \leq 0.025$).

4.3.5 Polyphenol effects on ethyl decanoate

Ethyl decanoate, a typical wine ethyl ester, was defined by a sensory panel as honey mead (Lund et al. 2007 or Appendix F). The perception of ethyl decanoate was reduced by all three of the polyphenols (Table 4.4). All of the polyphenols consistently suppressed the panellists' perception of the ester, although caffeic acid and catechin seemed to have a slightly greater effect. This finding corroborates previous research on esters by Aronson and Ebeler (2004) which showed that gallic acid minimises the sensory perception of the ester, ethyl benzoate. In that study, the

esters were interpreted as being bound to the polyphenols, thus reducing the panellists' perception of them.

Aronson and Ebeler (2004) found that polyphenols produced a greater reduction in the GC peak areas of long chain esters. For example, when a polyphenol was combined with ethyl hexanoate (C6) versus ethyl octanoate (C8) versus ethyl decanoate (C10), the reduction of the GC peak area was greatest with ethyl decanoate, which was the longest chain ester.

Table 4.4. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of ethyl decanoate using *R*-Index difference testing. (Bolded rows are the lowest concentrations of a perceivable difference.)

Poly-phenol in both Noise & Signal	Poly-phenol Amount (mg/L)	Ethyl deca-noate in Noise* (μg/L)	Ethyl deca-noate in Signal** (μg/L)	Difference of Noise & Signal (μg/L)	*R*-Index***	Significantly Different
None	0	0	600	600	0.640	No
None	**0**	**0**	**750**	**750**	**0.791**	**Yes**
Catechin	12	0	1000	1000	0.687	No
Catechin	**12**	**0**	**2000**	**2000**	**0.787**	**Yes**
Caffeic acid	102	0	1000	1000	0.647	No
Caffeic acid	**102**	**0**	**2000**	**2000**	**0.844**	**Yes**
Quercetin	10	0	750	750	0.660	No
Quercetin	**10**	**0**	**1000**	**1000**	**0.747**	**Yes**

* Noise (background) was defined as the diluted wine base with no ethyl decanoate added.
** Signal was defined as the diluted wine base with ethyl decanoate added.
*** *R*-Index critical =0.691 for N=15, unless otherwise stated ($P \leq 0.025$).

4.3.6 Volatiles and polyphenols

While astringency and mouthfeel have dominated much of the past research on polyphenols in wine, their interaction with the volatile compounds remains to be

explored in more depth. This research supported findings from previous sensory studies and found a similar increase in the suppression effect of specific Sauvignon blanc odour compounds in conjunction with their decreased degree of correlation of sensory attribute intensities and chemical concentrations (Table 3.5; Lund et al. 2009). In this case the influence of variable levels of polyphenols in commercial wines will lead to different suppression effects on the odour compounds present. For example, with a high coefficient of determination for 3MHA (r^2 = 0.73), there were minimal suppression effects on the perception of 3MHA when polyphenols were added. With a moderate coefficient of determination for 3MH (r^2 = 0.63), there was some suppression with catechin and quercetin additions and some accentuating effects on the perception of 3MH with caffeic acid additions**.** The lowest coefficient of determination (r^2 = 0.37) for IBMP, had the most severe suppression effects with catechin and caffeic acid additions, and to a lesser extent with quercetin additions. Each of the polyphenols reacted uniquely with each specific odour compound. Of the three polyphenols, catechin, showed the greatest suppression on three odour compounds, but it had a slight accentuation effect on 3MHA perception. The suppression of these volatile compounds in a wine matrix is not solely caused by polyphenols, but other compound present in the wine matrix. For example, Escudero et al (2007) found that ethanol masks ester compounds in red wine.

A recent study reported that polyphenols, such as the hydroxycinnamic acids (e.g. caftaric acid) are present at higher concentrations in free-run Sauvignon blanc juice, with little or no catechin or flavonols present (Maggu et al. 2007). In the same study, Sauvignon blanc juice made using prolonged skin contact and pressure contained minimal hydroxycinnammic acids but significant levels of quercetin-3-glucoside (10 mg/L) (Maggu et al. 2007). If more seeds and skins were left in the presence of juice, more catechin and quercetin glycosides would be extracted. Given the suppression seen of 3MH perception due to flavonoids such as catechin, but not seen with caffeic acid, the use of free-run juice is likely to accentuate the passionfruit skin/stalk character in Sauvignon blanc wine.

Winemaking practices, such as the use of oak to ferment or store wine, can introduce different polyphenols into the wine. Ibern-Gomez et al. (2001) reported that oak increases the concentration of polyphenols. Understanding the effects of polyphenols on odour perception can be used to create desired flavour profiles. Further research into different polyphenol concentrations and their suppression effects on odour compound perceptions needs to be conducted. This study begins

the exploration of sensory perception of interactions with non volatile and volatile compounds. Additional volatile compounds such as more esters and other key odour volatiles will need to be investigated.

Researchers in the past have attempted to use chemical analysis to predict sensory perceptions in wine. Aznar et al. (2003) examined the prediction of the sensory profile of 57 Spanish red wines from a chemical analysis of the odour compound groups (eg. methoxypyrazines). The study selected the highest correlating sensory descriptors and odour compound groups. These selected correlations were recorded at a range of 0.62 - 0.81. Commendably, they produced models that explained over 45% of the variance in the data, but the model only incorporated six sensory descriptor groups and unfortunately did not include three highly used sensory descriptor groups, which the panellists felt described the wines evaluated. The authors noted that wine is a complex medium, so that descriptors such as capsicum and green peppers that may not relate to high levels of methoxypyrazines but perhaps to other odour compounds too. In Chapter 3, I found that high IBMP concentrations did not correlate with high sensory perceptions of the expected capsicum attribute which also points to the complexity of wine and the fact that other flavour compounds contribute to the capsicum attribute while MIBP is being masked.

In the study of Aznar et al. (2003) there were many negative correlations that would indicate the presence of odour compounds that had a suppressing effect on the perception of other odour compounds. This notion of odour compounds suppressing other odour compounds could explain the accentuation of 3MH being caused by caffeic acid in this study. Caffeic acid could have bound with particular odour compounds that in the presence of 3MH suppress its perception. This current study demonstrated how non volatile compounds play a role in sensory perception of wine and may explain these negative or low correlations.

Analytical equipment such as Gas Chromatograph Mass Spectrometer (GC MS) or High Pressure Liquid Chromatograph (HPLC) can measure the concentration of a non volatile compound and the concentration of volatiles, but it does not measure the human perception effects of the interaction of volatile compounds with non volatile compounds. The results of this study support the inclusion of scientific sensory testing with chemical analysis to elucidate the perception of wine odour profiles. By integrating the two analyses, the more complete results will help to better interpret interactions occurring in the complex wine matrix.

4.4 Conclusion

The three polyphenols examined in this research showed varying effects on the key odour compounds in New Zealand Sauvignon blanc wine. The differences suggest that, currently, each compound needs to be evaluated singularly to fully understand its impact on the whole product or wine matrix. Considering that a wine can consist of 40 or more odour active volatile compounds as well as a range of non volatiles, this makes for a complex puzzle. Understanding the interaction of non volatile compounds, such as polyphenols, and their effects on volatile odour compounds enhances the prediction of flavour profiles through chemical analysis. It also aids winemakers in producing a wine with a desired odour profile.

CHAPTER 5

CONCLUSION

Trained panels are a valuable instrument from which to gain detailed knowledge of the perceptions of flavour. The goal of sensory research using trained panels is to interpret and understand the brain's perception of sensory information and apply it to human evaluation of products. This thesis reported on an array of research disciplines, including psychology, chemistry, and consumer science, with the use of sensory panels as the common integrating factor for the various components. Chapter 2 focused on understanding the motivation of trained panellists while Chapter 3 used a trained panel to characterise Sauvignon blanc flavours. Finally, in Chapter 4, the trained panel was used to improve the understanding of how compounds interact to enhance or suppress the sensory information.

5.1 Motivation of Sensory Panels

It is the goal of the sensory panel leader to get the most from the panel in terms of performance and results. The research in Section 2.4.1 begins to accumulate knowledge of panellists' motivation. The main findings were that people become panellists because of their general interest in food and/or because of the financial compensation. The key drivers for people to remain panellists were the enjoyment of being a panellist, a general interest in food, and/or the extra income. In the data collection, external panellists scored an increased degree of intrinsic motivation in comparison with internal panellists. Panellists with more experience rated themselves with a higher degree of perceived competence, which is essential to fostering intrinsic motivation (Deci and Ryan, 2000).

A better understanding of human behaviour will aid in improving panel training, panel interactions, and the social climate which can foster intrinsic motivation. Panel leaders might consider treating panellists as they would an athlete, in the respect that they want to motivate their panellists to peak performance levels at each panel session. According to the self-determination theory discussed in Section 2.2, the more a panellist/athlete is intrinsically motivated, the more likely she/he are to perform to the best of her/his ability (Deci and Ryan, 1985; 2000). This understanding of human behaviour is important because when panellists are intrinsically motivated in their work, they will experience increased enjoyment, well

being, and satisfaction, which, in theory, would lead to sustained participation and improved performance.

My research was able to adapt methodology from the psychology literature to measure intrinsic motivation. As stated in Section 2.2, fostering intrinsic motivation can lead to achievement of high performance. Future research will need to focus on correlating the degree of panellist intrinsic motivation with panellist performance to determine whether high ability in panel work is achieved. Panel performance levels could be assessed by measuring accuracy, consistency, and sensitivity, the three measurements commonly used to measure panellists' performance (Lawless and Heymann, 1999).

Success in correlating intrinsic motivation with performance would validate the application of the self determination theory, and allow the development of a more comprehensive understanding of panel motivation and performance. This validation of the self determination theory would also permit panel leaders to utilise the motivational tools of sports psychology used to enhance an athlete's optimal performance.

As stated in Appendix G, one difficulty with studying trained panel data is the need to assess data from more than one panel in order to achieve a statistically significant data set. Most trained sensory panels consist of eight to 12 individuals. Collaborating with other panels, as was done in Chapter 2 (Table 2.1), generated a sample size large enough to achieve the statistical validity required for accurate conclusions. The small sample size recorded in Appendix G prevented definitive conclusions from being drawn from those data.

A collaborating colleague, whose panel's data were part of results in Section 2.4.2, used the results from the questionnaire to determine where to increase the panel's overall intrinsic motivation. This collaborator was from General Mills and had an external panel that scored low in *value/usefulness,* and the panel leader took two actions to try to increase these scores. First, she changed corporate policy to include the panellists in company benefits such as use of the gym facility, and the objective was to make the panellists feel more connected to the company and valued enough to be included in company benefits. The second tactic she implemented to make the group feel useful and valued, was having upper management speak to panellists and point out the importance of the results from the panel, and the value of the panel to the company's success. This action gave them a connectedness that made them

feel part of the group, a factor part of intrinsic motivation discussed in Section 2.2. The panellists were then retested, and their scores for *value/usefulness* increased after these two actions (refer to Appendix I to see the presentation given at the Society for Sensory Professionals in November 2008).

Currently, panel leaders screen individuals for their sensory acuity. If intrinsic motivation can be proven to relate directly to higher performance for trained panellists, then further research could develop appropriate questionnaires to assess if candidates applying for panellist work possess adequate levels of intrinsic motivation necessary to become successful panellists. Consequently, panel leaders could directly target and screen candidates to recruit those individuals who exhibit high levels of intrinsic motivation.

In Section 2.4.1, one of the main reasons people became and remained panellists was because of their interest in food. Perhaps this criterion could be included in the screening questionnaire (e.g., "Rate your interest in food on a scale of 1 through 10, 1 being extremely low interest and 10 being extremely high interest"). This expanded screening procedure could assist in recruiting individuals with the sensory abilities and intrinsic motivations required to become excellent panellists.

Section 2.4.2 discusses how panellist experience, as well as panel type (internal and external), plays a role in motivation. These data indicate that there may be a decrease in intrinsic motivation that occurs after five to seven years of panel experience. If it can be shown that intrinsic motivation correlates to performance, then longitudinal studies extending beyond this five to seven year period could follow individual panellists, measuring intrinsic motivation and performance levels to confirm whether a panellist has reached a point at which he or she begins to lose interest in the panel tasks. If this correlation can be validated, then panel leaders could monitor a panellist's period of service and release him or her from further panel assignments before motivation decreases begin to adversely affect performance levels.

The research gathered in Chapter 2 was ultimately aimed to improve panel performance. Section 2.5.2 explored the use of alternative techniques derived from other research fields such as psychology, education and sports psychology. One of these methods is improved training methodology. As more adults enrol in continued education programmes, education research has focused on improving the training that educators receive when they are being trained to teach adults. Perhaps applying adult education techniques would enable panel leaders to shorten panel

training time, but the effectiveness of this strategy would need to be investigated by further study.

If the conclusions of the psychology literature are valid, and intrinsic motivation can be shown to be correlated to consistent levels of high performance, then one goal for panel leaders is to establish and maintain panels with high levels of intrinsic motivation, so they can benefit from high performing panels (Deci and Ryan 2000). Panel leaders can foster intrinsic motivation by acquiring panellists that are competent, and by conducting panel sessions in which panellists feel relatedness and experience autonomy in their task. Individual panellists can be motivated by different personal influences, so a panel leader must have a broad understanding of those motivational factors in fostering intrinsic motivation.

To achieve reduced operating costs, companies sometimes decide to require their employees to serve as sensory panellists (Word and Gress, 1981). In Chapter 2, external panels were determined to have higher motivation than internal panels. If it can be shown that higher levels of intrinsic motivation result in more accurate results, then the use of external panels might actually be more cost effective.

Alternatively, future research could determine why internal panellists exhibit a lower degree of intrinsic motivation. If decreased motivation level can be shown to be influenced by controllable factors, such as denying participating employees adequate additional time to complete their other work duties, companies could work to minimize these undesirable circumstances.

5.2 New Zealand Sauvignon blanc wine

The research in Chapter 3 substantiates the claim that when consumers taste a Marlborough Sauvignon blanc wine it exhibits distinctive flavours. This conclusion was determined and verified through a combination of sensory analysis, chemical analysis and New Zealand consumer preference data.

5.2.1 Sensory

The Sauvignon blanc wines tested in this study of the 2004 vintage showed significant differences between the Sauvignon blancs of New Zealand's Marlborough region and the Sauvignon blancs sampled from international wine producing regions. The 52 wines evaluated in Chapter 3 comprise one of the largest samplings of any comparable study found within the literature (Parr et al., 2007; Vilanova and Vilarino,

2006; Schlosser et al., 2005; Falque et al., 2004; Fischer et al., 1999; Cliff and Dever, 1996; Francis et al., 1994). Though the 2004 vintage of New Zealand Sauvignon blanc was studied extensively, the claim that Sauvignon blancs from Marlborough exhibit distinctive and unique flavours should be substantiated and validated through an investigation of subsequent Marlborough vintages (Appendix C; Lund et al., 2005; Lund et al., 2007).

Some journals require a fourth vintage before such conclusions can be drawn (as stated by a reviewer from the American Journal of Enology and Viticulture after receiving a manuscript based on the results the Chapter 3). Prior to the current study, a preliminary investigation of the 2003 New Zealand Sauvignon blanc vintage examined six sensory attributes (Sharpe, 2005). Those data supported conclusions that New Zealand Sauvignon blanc wines were high in sweet sweaty passionfruit, passionfruit skin, capsicum and grassy characteristics (Lund et al., 2005). Following the current study of the 2004 vintage elucidated in this thesis, a subsequent study of the 2005 New Zealand vintage was conducted (Appendix F). Investigation of the 2005 vintage measured Marlborough Sauvignon blanc wines as having higher intensities of tropical, sweet sweaty passionfruit, capsicum, passionfruit skin, stonefruit, and apple characteristic; findings that further corroborate the 2004 vintage study results.

A fourth vintage of three 2006 Marlborough Sauvignon blanc wines were examined by the trained panel. The three wines exhibited the same core flavour profile as reported from previous Marlborough vintages, with high levels of passionfruit, tropical, capsicum, and passionfruit skin. Another researcher found results that further support these results. Parr et al. (2007) found winemakers could distinguish seven 2004 Marlborough wines from three 2004 French wines via an ortho- and retro-nasal assessment. Based on the conclusion from these four vintages, one might postulate that future vintages of Marlborough Sauvignon blanc wines could be expected to exhibit similar characteristics of fruity (passionfruit, tropical) and herbaceous (capsicum, passionfruit skin), but there would be some variations in flavour profiles, due to variations in seasonal growing conditions, changes in weather patterns, changes vine maturity, and other environmental factors. As an example from the 2005 vintage, there were more wines with apple lolly and honey mead characteristics than fresh and canned asparagus exhibited in the 2004 vintage wines (Appendix F).

Based on the results in this thesis, regional differences were also discernable among New Zealand Sauvignon blanc, especially between the wines from Hawke's Bay and the wines from Marlborough. Wairarapa wines were somewhat more similar to wines from Marlborough, but exhibited more green characteristics, and the consumer data suggest that New Zealand consumers preferred the Marlborough wines to Wairarapa wines. The studies of the 2003 vintages also revealed some distinct sensory differences between the Sauvignon blanc wines produced from these three New Zealand regions (Sharpe, 2005). These differences among the three regions were the reason for their inclusion in the 2004 vintage study. The 2005 vintage also yielded similar results as reported in this thesis for the 2004 vintage except the Wairarapa wines had less similar characteristics with Marlborough wines (Appendix F).

The different flavour profiles for the different vintages were elucidated from a lexicon of odour terms specific to Sauvignon blanc wines. The lexicon and reference standards were developed as part of the sensory panel's training and used to direct the panel's subsequent analyses. These descriptive terms have been adapted into an aroma wheel for Sauvignon blanc, which has been distributed to numerous wineries in New Zealand (Appendix A). In addition, the lexicon of Sauvignon blanc descriptors and a derived set of reference standards have been adopted by wine sensory researchers at the Universidad de Catolica in Chile.

Collaborations among the wine research teams in Chile, Australia, France, South Africa and the USA could be used to assess whether these international panels arrive at comparable data when they all apply the same sensory attribute descriptors and reference standards. A further benefit from these collaborations would be the accumulation of an extensive data set, derived from panellists representing a wide range of training protocols, a wide range of cultural and experiential backgrounds, and from data acquired using a wide range of analytical equipment. Combining this data should give a very robust validation of the correlation of sensory data and chemical analyses. These collaborations could also be employed to promote the standardisation of practices and methodologies.

Future work within the Sauvignon blanc programme in general should seek to determine what aspect of *terroir* is affecting the flavour characteristics in the Marlborough Sauvignon blanc, in order to aid the industry in developing new styles. *Terroir*, as defined by Moran (2006), includes many things: i.e. the soil, the weather, the sunlight, the temperature and many other factors. Studying *terroir* is complicated

by the fact that there are many variables to control. Another difficulty is that some factors may not effect biological changes in grapes in the current year of testing, but the fruit may be altered in the following year. Viticulturists continue to research and control as many variables as possible to better understand the effects of their manipulations.

Goode (2006) stated that Sauvignon blanc is a cool climate grape. Regions such as Adelaide in Australia and California in the USA experience cool periods, but in general their temperatures are higher than those recorded in Marlborough (Jones, 2007). The results in Chapter 3 showed that Marlborough wines exhibited higher concentrations of acid compared to other regions' wines. Cooler climate wines are attributed with higher acidity due to less of the acid being respired during the berry growing cycle (Amerine and Singleton, 1977). The increased acidity may alter the perception of some of the volatile compounds. During storage, 3MHA declines in concentration at a more rapid rate than 3MH (Herbst et al., 2007). This process is accelerated in acidic conditions, yielding wine with reduced levels of the high sweet, sweaty passionfruit characteristics of Marlborough wines. Measuring the flavour perception of the thiols at different acid levels may show even though concentrations are decreasing, the higher acid levels may increase sweet sweaty passionfruit perception. Another experiment might include measuring how the flavour profile changes sensorially and chemically over the shelf life of a Marlborough cool climate Sauvignon blanc wine, compared with an Australian hot climate Sauvignon blanc wine, could give further information on how acidic conditions influence changes in wine flavour. These flavour changes would be influenced by both the decrease in 3MHA and any other flavour compounds affected by acidic conditions.

Acidity is not the only difference between cool and warm climate wines. Allen (2006) reported cool climate wines as having higher MIBP concentrations than those measured in warm climate wines. A study evaluating grapevines grown in Marlborough soil, but in a greenhouse environment under different controlled temperatures, could yield grapes with different levels of MIBP and other flavour compounds. This experiment would attempt to simulate warm climate and cool climate conditions.

5.2.2 Consumer

New Zealand consumers preferred New Zealand Marlborough Sauvignon blanc to the international Sauvignon Blanc wines tested in this study (Chapter 3). New

Zealanders are very familiar with Sauvignon blanc, and it was the most frequently consumed and the most frequently purchased white wine among this group of consumers. Their familiarity with the wine quality could have aided them in distinguishing the differences and determining preferences among different Sauvignon blanc wines in a blind tasting situation. In a parallel USA study of the 2005 vintage, there was not as clear a delineation in preferences for the different Sauvignon blanc wines (Appendix F). The USA consumer listed Sauvignon blanc wine as the fourth most preferred white wine varietal (tied with sparkling wines), with Pinot gris, Chardonnay and Riesling the more preferred wine varietals. Consumers from additional international markets should be tested to determine if a level of familiarity inclines consumers to prefer Marlborough style of Sauvignon blanc over other wines. This investigation could aid wine marketers in the increasing the consumer consumption of wine through the understanding of how consumer familiarity of the product correlates to their purchase/consumption patterns.

Past research by Pliner (1982) indicated that hedonic response increased after ten exposures to a novel food. More recent work by Williams et al. (2008) showed that hedonic scores could increase with even fewer exposures, depending on the product. Wine was not included in either of these studies. A future line of research could test people who are Sauvignon blanc consumers and compare them to non-Sauvignon blanc consumers. If Sauvignon blanc consumers can delineate the different styles and the non-Sauvignon blanc consumers cannot, then wine marketers' first priority might be encouraging consumers to drink Sauvignon blanc, and then they can focus on promoting the Marlborough rendition as a premium brand of Sauvignon blanc. If the ability to discern different styles of Sauvignon blanc leads to increased levels of consumer preference, then the winemakers need to craft a distinctive style that is easily distinguishable by the consumer's palate. A study to explore familiarity and hedonic scores of wines could extend the exploration of how consumers become involved with consumer products.

Extending the consumer research of New Zealand Sauvignon blanc to include new markets, such as the Asian market, could add value to wine consumer research. This new market has huge potential for growth with the increasing wealth of the Asian population. As it is not yet an important part of their culture, the average Asian consumer would have little knowledge of wine produced from grapes, in contrast to consumers in a country such as France (Beverland, 2002). The French knowledge base around wine may also be very different from the New Zealand culture, which

has more recently embraced wine as part of everyday life. An interesting study might include assessing wine knowledge in these three cultures, which are at very different stages of including wine as part of their everyday lives. Wine knowledge could include knowledge of different varietals, flavour characteristics of those varietals, advantages or disadvantages of corks, defects in wine flavour, and other aspects of wine appreciation. This study could be used to investigate how knowledge about a product influences consumer preferences for that product. The proposed study would have a series of questions for each market (France, New Zealand and China) that would be based on measuring wine knowledge over a defined period (0 y, 5 y, 10 y). Increased information of how product knowledge is disseminated into a target consumer market and subsequently acquired by consumers could facilitate other new product introductions. Simultaneous testing of consumer preferences in these markets (France, New Zealand and China) would yield how product knowledge interrelates with consumers' preferences and how these two factors develop and evolve longitudinally. This type of research would also extend the exploration of how consumers become involved with consumer products as stated in the previous paragraph when conducting familiarity research.

5.3 Perception interactions

The consumer's sensory experience of a wine influences their degree of preference for that wine. "It is possible for two samples to be chemically different in formulation, but for human beings not to perceive this difference" (Lawless and Heymann, 1999). This is a simple but profound statement. In Chapter 4, the three polyphenols were found to have dissimilar effects on the key odour compounds in New Zealand Sauvignon blanc wine. At this point there is no simple predictable effect that can be applied to a compound as a rule (e.g. 'All polyphenols suppress perceptions of thiols'). Rather, each compound needs to be evaluated singularly to understand its impact on the whole product /wine matrix. Considering that a wine variety can consist of 40 or more active aroma compounds, with many more that do not directly affect aroma, this situation creates the potential for a large number of combinatorial effects.

Understanding the interaction of non-volatile compounds, such as polyphenols, and their effects on volatile aroma compounds, enhances the prediction of flavour profiles through chemical analysis. Ferreira et al. (2007) suggests that there is a "barrier" of primarily non volatiles but also volatile compounds that definitive volatiles need to break through to be perceived. The results from this thesis show that the

polyphenols may be part of this barrier. Future studies should include identifying other compounds that limit the perception of the volatiles. Collaborations would be valuable and perhaps essential, as this testing takes a large amount of time and effort, as well as being expensive. Teaming with other research organizations would streamline this process.

Understanding the disparity between the value of an odour compound's detection threshold (the lowest concentration at which a panellist can perceive a stimulus) and its recognition threshold (the lowest concentration at which the panellist can descriptively identify that stimulus) is critical to achieving a correct determination of impact compounds. Whereas it might be assumed that the relative value of an odour compound's detection threshold can be used predict its subsequent effect as an impact compound, recent studies conducted with the trained panel in this thesis demonstrated that the relationship between a compound's detection threshold and recognition threshold may not show a linear correlation. MIBP has a very low detection threshold of 1 ng/L, in comparison to 3MH, which has a much higher detection threshold of 23 ng/L. Yet both of these compounds share the same recognition threshold of 125 ng/L. (Appendix H). Analytical chemists principally rely on detection thresholds in their attempts to understand the impact of a flavour compound on a wine's aroma profile (Tominaga et al., 1998b; Tominaga et al., 2000; Aznar et al., 2003; Falque et al., 2004; Tominaga and Dubourdieu, 2006; Escudero, 2007). Recognition thresholds may indeed play a more influential role on determining the sensory attributes of a wine's profile. Yet these recognition threshold values are rarely measured or considered in this process.

Recognition thresholds are also more important to the consumer. If a wine is different from another wine and the consumer can describe why it is dissimilar, the resultant consumer language is more powerful in engaging the end product user. Future research should determine if recognition threshold plays a more significant indication of flavour impact of a compound than detection thresholds. Currently, analytical chemists use the calculation of the odour activity value (OAV) to determine the degree of impact a chemical compound delivers in a product's flavour profile (Drake et al., 2006). The OAV is calculated by comparing the chemical compound's concentration to the detection threshold. Perhaps if the recognition threshold was used in this ratio instead of detection threshold, the new OAV may be more predictive of the flavour impact of a compound.

Marlborough wines have high acidity levels, a consideration that needs to be kept in mind when measuring sensory perceptions. A higher acidity may influence the perception of the thiols as it might promote covalent binding between the polyphenols and volatiles. Acidity will have an effect on cleaving or enhancing bonds between compounds. Examination of the perception effects of polyphenols with thiols, MIBP and ethyl decanoate when the titratable acidity is high (7-10 g/L versus the 2-5 g/L concentration actually used) would also be of value. The higher acidity levels reflect actual concentrations in Marlborough wines (7-10 g/L) while the international wines have lower concentrations (2-5 g/L).

The chemical data in Chapter 3 showed correlation of three chemicals (3MHA, 3MH, MIBP) to some of the sensory attributes, with the thiols showing the highest correlations (Table 3.4). The work described in Chapter 4 is likely to have affected these correlations. For example, in Table 4.1 MIBP was shown to be masked by all three of the polyphenols tested, which may help explain why MIBP had the lowest coefficient of determination with its counterpart sensory attribute in the wine (capsicum, r^2=0.57). In contrast, 3MHA had high coefficient of determination value with its counterpart sensory attribute, sweet sweaty passionfruit, and it exhibited little to no masking by the three polyphenols. Obviously, wine is a complex media with more than three flavour compounds and three non volatile compounds. Additional research could evaluate the synergistic/masking effects of MIBP in the presence of the thiols, 3MH and 3MHA.

As stated in Chapter 4, the other Sauvignon blanc esters need to be further investigated for their influence on the flavour profile of Marlborough Sauvignon blanc, considering interference effects, masking effects, or other interactions. Starting with ethyl hexanoate and amyl acetate is suggested, as these compounds are at higher concentrations in Marlborough Sauvignon blanc (Benkwitz et al., 2007). After determining the chemical concentrations of ethyl hexanoate and amyl acetate, it would be advantageous to correlate these analyses with the corresponding sensory attributes (floral herb and banana lolly, respectively). The detection threshold in wine, as well as the effects of the polyphenols on these esters, should also be examined. Future investigations into the chemical analyses of Sauvignon blanc wine continue with additional esters, such as other ethyl butanoate, ethyl decoanoate, and hexyl acetate, which also been shown to contribute to the fruity and floral characteristics (Benkwitz et al., 2007). C6 compounds (hexan-1-ol, cis-2-hexenol,

cis-3-hexenol, trans-2-hexenol, trans-3-hexenol) are also important for their contribution to the green, earthy, and apple characteristics.

Evaluation of the perception of volatiles in the presence of a glycosidic quercetin would be interesting in comparison with the results reported in Chapter 4 with the unprotected quercetin. The glycosidic quercetin is a form resembling the compound that is present in white wine.

A more accurate statistical model could be generated from the larger number of chemicals analysed. This model could be used to predict Sauvignon blanc flavour profiles using chemical analysis. The compounds which do not contribute to the statistical model and have high concentrations would indicate they are masked in the wine matrix. The statistical model has been conducted and will be written in a paper with collaborators from University of Auckland Wine Science Chemistry lab.

Understanding the human perception of aroma compounds, which might interact with other chemical compounds, will yield data that will aid in a better understanding of wine profiles. Eventually this information may lead to the ability of researchers to be able to predict wine aroma profile from the knowledge of the constituents of a grape.

5.4 New areas of research

More work should explore the interactions of volatile chemicals of Sauvignon blanc and their effect on human perception. More specifically, esters such as ethyl hexanoate (floral herb) appear to play an important role in New Zealand Sauvignon blanc and should be further studied. Defining non volatiles other than polyphenols and testing their effects on human perception would give more insight into understanding the wine matrix. Furthermore, performing sensory studies on Sauvignon blanc juice and correlating with the sensory evaluation of finished wine would aid the understanding of the flavour changes that occur during fermentation.

Other researchers continue to develop a better understand the regional flavour profiles of Marlborough wines, but at a more granular level. The Marlborough region is producing more wine and growing in acreage, and this means different soils and climatic effects. An early experiment of Parr et al. (2007) determined that winemakers could not determine a difference among three sub-regions of Marlborough (Brancott Valley, Rapaura and Awatere). Future work by this team

continues looking at winemakers' perception of five sub-regions of Marlborough. As this region grows and diversifies more, sub-regional flavour profiles may arise due to different soil types and climate. Lastly, evaluating the effects of different yeasts on the flavour profile of New Zealand Sauvignon blanc wine could aid in the understanding of the distinctive characteristics in the Marlborough wines.

5.5 Concluding remarks

The strength of the sensory science field lies in the process of using people as instruments. A machine such as a GC MS is accurate in the measurement of chemical compound concentrations, but it does not necessarily correlate with what is actually perceived by the human brain. The use of sensory panels as a research tool gives more accurate insight into what humans perceive in products. This research has touched on unravelling the complexity of wine, but there are many aspects yet to be fully understood. Further sensory analysis needs to be conducted to enable the understanding of the changes that occur when different chemical compounds are present in mixtures. Until a machine is developed that is able to replicate the human olfactory system and the brain's interpretation of the information received, researchers will need to rely on humans to reveal this information.

Whereas using humans as an instrument in sensory analysis is the strength of the science, it is also the weakness. The brain is a complex organ (Abdi, 2002; Prescott, 1999), and the cognitive processes that panellists undergo when perceiving an odour or taste are not well understood. Through measuring synapses in the brain, Italian researchers found that when a novice wine drinker tastes wine, the pleasure part of their brain is stimulated, whereas, when an expert wine connoisseur samples wine, the language area of the brain is stimulated (Goode, 2006). Understanding the intricacy of how the brain interprets sensory information, and how this is affected by the individuality of each panellist, poses one of the greatest challenges to the sensory science field.

The initial study from this thesis in panel motivation can be used as the foundation to build this new research in sensory science to aid the quest for improved quality data. My wine flavour investigation in this thesis has helped to begin to understand the sensory perception of Sauvignon blanc, in parallel with the chemical analysis. I have made a good start to understanding the key attributes and chemicals that make New Zealand Sauvignon blanc different. However, Sauvignon blanc, like most other wine, is a complex solution with many interactions still waiting to be determined, and with

many challenges remaining in the linking of chemical and sensory analysis with perception of aroma by the brain.

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APPENDICES

Appendix A. NEW ZEALAND SAUVIGNON BLANC WINE WHEEL

Appendix B. DESCRIPTIVE ANALYSIS OF SAUVIGNON BLANC WINE EVALUATION FORM FOR 2004 VINTAGE

Flavour Components

Name:_____

Sweet Sweaty/ Passionfruit _____

Absent Extreme

Capsicum _____

Absent Extreme

Cat's pee _____

Absent Extreme

Passionfruit Skin_____

Absent Extreme

Grassy_____

Absent Extreme

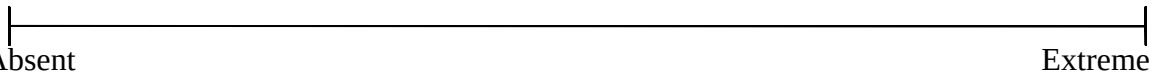
Flinty /Mineral _____

Absent Extreme

Citrus _____

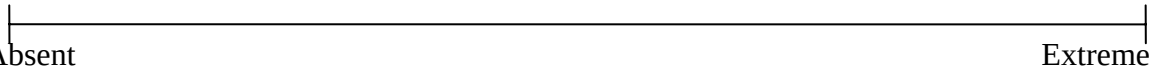
Absent Extreme

Bourbon_____



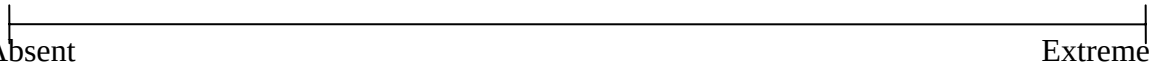
Absent Extreme

Apple Lolly _____



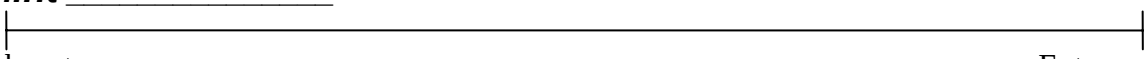
Absent Extreme

Tropical _____



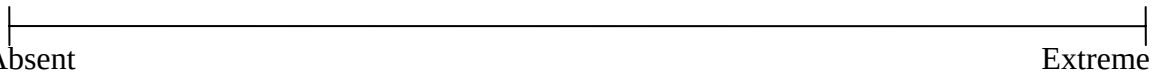
Absent Extreme

Mint _____



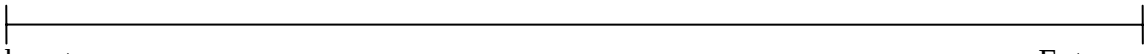
Absent Extreme

Fresh Asparagus_____



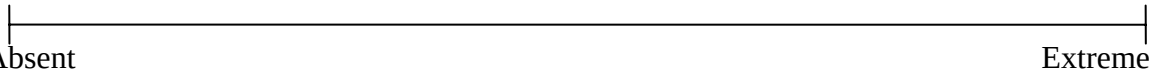
Absent Extreme

Canned Asparagus _____



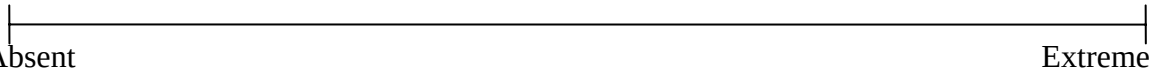
Absent Extreme

Stonefruit _____



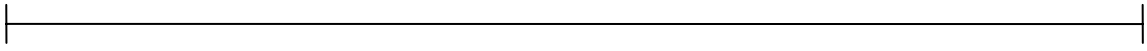
Absent Extreme

Apple _____



Absent Extreme

Snow Peas _____



Absent Extreme

Appendix C. PUBLICATION: EFFECT OF SCREWCAP AND CORK CLOSURES ON SO_2 LEVELS AND AROMAS IN SAUVIGNON BLANC WINE

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Effect of Screwcap and Cork Closures on SO_2 Levels and Aromas in a Sauvignon Blanc Wine

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The development of a Sauvignon Blanc wine sealed under screwcap and cork was undertaken using different fill heights and initial levels of free SO_2 (20, 25, and 30 mg/L) over 2 years. More SO_2 was lost for wines under cork over the first 3 months, corresponding to a higher level of dissolved oxygen at bottling. From this time wines under cork and screwcap lost SO_2 at a similar rate and retained dissolved CO_2 equally well, indicating that both types of closure presented a similar effective barrier to gas movement. After 2 years in the bottle, the different treatments retained similar levels of the volatile thiols 3-mercaptohexyl acetate (3MHA) and 3-mercaptohexanol (3MH) responsible for fruity aromas, with initial SO_2 levels having no effect, but the thiol concentrations were 18−23% lower under cork, which may be due to absorption of volatiles into the cork. Levels of polyphenols such as caftaric acid and the absorbance at 420 nm were the same for wines under cork and screwcap, whereas some indication was given that more oxidation occurred with a lower level of initial free SO_2. Although the different treatments were not readily distinguished by a sensory panel, the data for individual wines showed a positive correlation between passion fruit descriptors and levels of 3MHA and 3MH.

KEYWORDS: Sauvignon Blanc; screwcap; cork; closure; wine aging; sensory analysis; polyphenols; volatile thiols

INTRODUCTION

Cylindrical corks have been the closure of choice in glass wine bottles for several centuries. However, winemakers have been led to seek alternatives due to a number of problems with cork, including taint arising from trichloroanisoles (TCA) (*1*) and natural variability in permeability to gases leading to sporadic bottle oxidation. A range of synthetic cylindrical closures are currently available (*2*), and although these eliminate the incidence of cork taint, other closure components can migrate into the wine over time, they are more permeable to oxygen, and plastic materials can absorb volatiles from the wine.

The screwcap closure, also known as the roll-on tamper-evident (ROTE) closure, creates an airtight seal around the rim of the bottle as opposed to the inner surface of the bottle neck. The inner liner of the screwcap typically consists of a 19 μm PVDC film in contact with the wine, a 20 μm layer of tin foil as a gas barrier, and a 2 mm polyethylene wad to maintain compression. Although screwcaps have been used commercially for over 30 years, their use with higher value wines stems from the bottling of 2000 Riesling by winemakers in Clare Valley, South Australia. Over a short period of time, winemakers in New Zealand have shifted from bottling practically none of their wines under screwcap to ~70% of wines in 2005, largely through the efforts of the New Zealand Screwcap Wine Seal Initiative established in 2001 (*3*, *4*).

Few studies have been published in which comparisons have been made between wines under cork and screwcap. Trials conducted in Australia in the 1970s on the new Stelvin closures with red and white wines showed that wines under screwcap retained more sulfur dioxide after 18 months in the bottle than under cork and received higher quality scores (*5*, *6*). A major trial at the Australian Wine Research Institute on a Semillon wine from the Clare Valley has involved a comparison of 14 different closures, including natural corks and screwcaps (*7*). In this study the wine under screwcap recorded the lowest drop in SO_2 and ascorbic acid and the least browning (visible absorbance at 420 nm), all pointing to the lowest level of wine oxidation, whereas in sensory tests the screwcap wine was highest in overall fruit and lowest in developed and "oxidized" characters. However, after 18 months of bottle storage, a new negative aroma described as "reduced" or rubbery was noted and was observed to be most intense in the wine under screwcap. It was suggested that having a higher filling height and more

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Table 1. Levels of Dissolved Oxygen at Day 1 and SO_2 after 23 Months for the 12 Wine Treatments ($n = 4$)[a]

wine treatment	fill height, mm	target initial free SO_2, mg/L	DO at 1 day, mg/L	free SO_2 at 23 months, mg/L	total SO_2 at 23 months mg/L
1, screwcap	20	20	0.78 (±0.08)a	12.3 (±0.5)a	109 (±1)a
2, screwcap	25	20	0.63 (±0.11)a	11.8 (±1.0)a	108 (±1)a
3, screwcap	30	20	0.63 (±0.13)a	10.8 (±0.5)ab	107 (±1)ab
4, cork	10	20	1.33 (±0.34)b	9.0 (±1.4)b	104 (±3)b
5, screwcap	20	25	0.59 (±0.06)a	14.5 (±1.3)c	115 (±1)c
6, screwcap	25	25	0.61 (±0.06)a	14.0 (±0)ac	114 (±1)c
7, screwcap	30	25	0.66 (±0.03)a	13.5 (±0.6)ac	113 (±1)c
8, cork	10	25	1.10 (±0.25)b	11.8 (±1.7)a	108 (±5)a
9, screwcap	20	30	0.63 (±0.10)a	17.3 (±0.5)d	118 (±1)d
10, screwcap	25	30	0.62 (±0.02)a	16.3 (±0.5)cd	118 (±1)cd
11, screwcap	30	30	0.66 (±0.08)a	14.0 (±0)ac	115 (±1)cd
12, cork	10	30	1.14 (±0.36)b	12.3 (±3.3)a	112 (±3)ac

[a] Standard deviations are given in parentheses after each value. Values followed by different letters are statistically different (ANOVA, Fisher's $LSD_{0.05}$).

oxygen at bottling, or using a treatment to remove sulfides prior to bottling, may have avoided the occurrence of this flavor attribute (*7*).

This study was initiated by the New Zealand Screwcap Initiative to provide practical guidelines for bottling wines under screwcap. Most wineries use free SO_2 in the order of 25−30 mg/L for wines bottled under cork, but with the prospect of less oxygen ingress under screwcap, many were considering using slightly less free SO_2 at bottling. In this trial, a 2002 Marlborough Sauvignon Blanc, a leading white wine from New Zealand, was bottled under cork and screwcaps with three different fill heights (20, 25, and 30 mm) and treated with three initial levels of free SO_2 (20, 25, and 30 mg/L). The decline in SO_2 levels was monitored 4, 10, and 23 months after bottling; at 23 months samples were also taken for further chemical and sensory analysis of parameters related to Sauvignon Blanc aroma and wine oxidation (*8*−*10*).

MATERIALS AND METHODS

Sauvignon Blanc grapes were mechanically harvested in Marlborough, New Zealand, at 22.8 °Brix, titratable acidity of 8.7 g/L, and pH of 3.12. After crushing and destemming, the free run juice coming from a pneumatic press was fermented with Prise de Mousse yeast (Lalvin EC1118) at a temperature of 10−13 °C for ~3 weeks at Foxes Island Wines, using standard Marlborough winemaking techniques. Bentonite was added during fermentation, but there were no ascorbic acid additions and no oak contact. The wine was bottled at Kumeu River Wines, Auckland, on October 17, 2002, at which point it had a titratable acidity of 7.9 g/L, a pH of 3.22, an alcohol content of 13.0%, and a residual sugar level of 4.5 g/L. The wine was filtered through Sietz SD100 lenticular filters and a 0.65 μm membrane filter prior to bottling. The wine was separated into three 167 L lots, and sulfur dioxide was added to target levels of 20, 25, and 30 mg/L free SO_2. The wine was bottled under cork (44 × 24 mm, super grade, hydrogen peroxide treated) at a single fill height of 10 mm (being the distance from the bottom of the cork to the liquid level at bottling), and under Stelvin brand screwcap with Saran−tin liners (Esvin Wine Resources, Auckland, New Zealand) at fill heights of 20, 25, and 30 mm (the distance from the rim of the bottle or screwcap liner to the liquid level). Forty-eight bottles of each of 12 wine treatments (**Table 1**) were numbered and randomly stored within treatments in an underground concrete cellar with a temperature of 6−14 °C and a relative humidity of ~80%. The screwcap-sealed bottles were stored upright, and the cork-sealed bottles were stored lying down.

Dissolved Oxygen (DO) and Carbon Dioxide. Measures of DO were made using an Orbisphere 3650 meter on four bottles of each wine treatment. Immediately after the bottles were opened, 250−300 mL of wine was pumped through the Orbisphere meter using a peristaltic pump. A further probe and second Orbisphere meter were used in series alongside the DO meter to measure levels of dissolved CO_2.

Sulfur Dioxide. Levels of free and total SO_2 were determined for four bottles of each treatment using the aspiration method (*11*).

For three of the treatments (3, screwcap, 30 mm fill height, and 20 mg/L initial free SO_2; 11, screwcap, 30 mm fill height, and 30 mg/L initial free SO_2; 12, cork, 30 mm fill height, and 30 mg/L initial free SO_2) the following chemical and sensory analyses were undertaken in triplicate once the wines had been in the bottle for 2 years. Three bottles from each treatment were split into six 375 mL bottles under nitrogen and stored at 4 °C. Within 7 days wines from the same bottles were used for both chemical and descriptive sensory analyses. Wine from new bottles were used for difference sensory testing, which was conducted in the same week as the descriptive analysis.

Volatile Thiols. The method of Tominaga et al. was used to determine the level of 3-mercaptohexyl acetate (3MHA) and 3-mercaptohexan-1-ol (3MH) (*9*), using 4-methoxy-2-methyl-2-mercaptobutane as an internal standard. The thiols were extracted from the wine using *p*-hydroxymercuribenzoic acid, which was then fixed onto an anion exchange column before the thiols were eluted with cysteine and extracted into dichloromethane prior to concentration and manual injection of 4 μL onto an Agilent 6890N GC with an Agilent 5973 MS detector. The thiols were separated on a 50 m BP20 capillary column (220 × 0.25 μm) using He carrier gas at 28 cm/s and an oven temperature ramping from 40 to 220 °C for a 71 min run. Standard curves were obtained by adding increasing quantities of the two volatile thiols to a Sauvignon Blanc wine (50−500 ng/L of 3MHA; 500−5000 ng/L of 3MH). The correlation coefficient (R^2) was 0.990 for 3MHA and 0.997 for 3MH. The reproducibility of the method was evaluated by repeating the analysis of the same Sauvignon Blanc wine six times under constant operating conditions. Relative standard deviations of 6 and 5% were obtained for 3MHA and 3MH, respectively.

Visible Absorbance. The absorbance at 420 nm was measured on a Cary 50 UV spectophotometer and was used to indicate the degree of brown color of the wine (*12*).

HPLC Analysis. Monomeric wine polyphenols were determined using an HPLC method previously outlined (*13*). In brief, 20 μL of filtered wine was injected onto a Phenomenex Luna C18 column (4.6 × 250 mm, 5 μm particle size) on an Agilent 1100 series instrument with a diode array detector set at 280 nm (for flavan-3-ols), 320 nm (for hydroxycinnamic acids), and 365 nm (for flavonols). A ternary solvent was run over 2 h employing water, 5% aqueous acetic acid, and acetonitrile. The main polyphenols targeted were caftaric acid (the hydroxycinnamic acid present in highest levels) and *S*-glutathionyl caftaric acid (known to form during the enzymic oxidation of caftaric acid in crushed grapes in the presence of glutathione).

Sensory Analysis. Twelve trained panelists performed the sensory evaluation of the wine in booths with daylight lighting at the HortResearch Sensory and Consumer Science Facility in Mount Albert, Auckland, New Zealand. The panelists were trained for 50 h using traditional sensory methodology to evaluate Sauvignon Blanc. A positive airflow was maintained in the booths to reduce any odors not associated with the wine. Three-digit codes were put on the wine glasses to remove any identification of samples. Approximately 20 mL of wine was presented in standard XL wine glasses with watch glass lids. Wine was served at room temperature (20 °C). Panelists used double-filtered (Microlene) water and crackers as a palate cleanser.

The panelists assessed the wines with an *R*-index difference test. Coded samples were presented in a balanced design of pairs for each of the four possible combinations of wines, which for three wine treatments yielded a total of 24 wine samples (AA, AB, BA, BB; AA, AC, CA, CC; BB, BC, CB, CC). The panelists were asked whether the wine pairs were "different" or the "same", and if their judgment was "sure" or "unsure". *R*-index values (R_i) were calculated, and R_i-50% results were compared to the critical value for a two-tailed test at a level of significance of 5% that the result is greater than chance, that is, a critical value of 18.9% for $N = 24$ (*14*, *15*).

The panelists also provided a sensory profile of the three treatments of wines using attributes developed by the panel to describe New

Zealand Sauvignon Blanc wines. The panelists also supplied further descriptors of the wines to lessen the "dumping effect" (incorrectly assigning a "new" attribute to one of the small number of descriptors available), but were not asked to look specifically for "reduced" or rubbery odors. Triplicate samples were presented monadically in a balanced design (i.e., each panelist described the wine from nine different bottles). The descriptors and their reference compounds were as follows: sweet-sweaty-passion fruit (3MHA), passion fruit skin-stalk (3MH), capsicum (isobutyl-methoxypyrazine), cat urine (4-mercapto-4-methylpentan-2-one), grassy (*cis*-hexan-1-ol), and lemon peel (1 cm^2 of a Yen Ben cultivar). The panelists used an unstructured 150 mm line scale to rate the intensities of each attribute.

The results were analyzed using a two-factor (wine and panelist) analysis of variance. For each sensory descriptor p values were determined to see if a level of significance of 5% had been achieved. A principal component analysis (PCA) was undertaken using The Unscambler (v 9.1a, CAMO Process AS) to associate the six sensory descriptors and six chemical components as active variables for the nine different bottles of wine. All of the descriptors were normalized using the correlation matrix for the analysis.

The various chemical analyses are reported plus or minus the standard deviation of the results. Statistical analyses of the chemical data were also undertaken using ANOVA single factor (Microsoft Excel, 2002) and Fisher's least significant difference ($LSD_{0.05}$).

RESULTS AND DISCUSSION

The day after the wine was bottled, levels of DO were found to be in the range of 0.5−0.9 mg/L for the screwcap-sealed wines, whereas significantly higher and more variable levels of 0.8−1.6 mg/L were seen with the cork seals (**Table 1**). The bottling machine did not have pre-evacuation or inert gas sparging, so the DO level was influenced by the flow geometry of each filling head, which will differ to some extent. On the other hand, the corking head did have a vacuum facility, but the DO readings on the subsequent day showed that this was quite variable in efficiency. This meant that the cork could act as a piston to compress air into the wine in a variable manner, leading to higher DO values than for the screwcap-sealed wines. Oxygen included within the mass of the dry cork may also diffuse into the wine, particularly during the initial weeks of storage (*16*). After 4 and 10 months in the bottle, when four bottles of each treatment were again sampled, all DO readings were below 0.01 mg/L and were equally low under cork as under screwcap.

Levels of CO_2 were similar across the 12 treatments the day after bottling, and the wines sealed with cork recorded 96 ± 4% of the overall average CO_2 value. With subsequent testing, the CO_2 readings, in the range of 0.7−1.0 g/L, were again very uniform across treatments, and after 4 months in the bottle, the cork-sealed wines averaged 95 ± 3% of the average value; again, after 10 months in the bottle, cork maintained 96 ± 5% of the overall average CO_2 reading. These results indicate that cork was acting as an effective gas barrier, with similar gas retention to the screwcap seal.

Changes in total SO_2 levels are a good indicator of the occurrence of oxidation in wine (*7*). The initial levels of SO_2 in the 167 L wine lots for each of the target levels were as follows: for a target level of 20 mg/L, measured levels of 22 mg/L free and 126 mg/L total SO_2 were obtained; for a target of 25 mg/L, 26 mg/L free and 131 mg/L total; and for a target of 30 mg/L, 31 mg/L free and 136 mg/L total SO_2. The decline in total SO_2 over the first 4 months in the bottle was greatest with cork (12 ± 2% average loss compared to 9 ± 1% for screwcaps) (**Figure 1**), consistent with the higher initial DO levels. For wines under screwcap more SO_2 was lost with a larger initial headspace volume. One of the bottles under cork

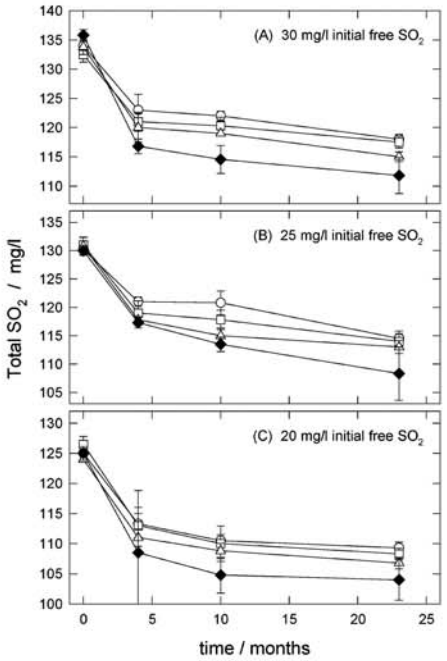

Figure 1. Decrease in levels of total SO_2 for Sauvignon Blanc wines bottled initially with (**A**) 30 mg/L free SO_2, (**B**) 20 mg/L free SO_2, and (**C**) 20 mg/L free SO_2: (○) screwcaps, 20 mm fill height; (□) screwcaps, 25 mm fill height; (△) screwcaps, 30 mm fill height; (◆) corks, 10 mm fill height (n = 4). Error bars are given for the standard deviation in each value.

produced a much lower value of 93 mg/L, giving rise to the large error bars for this point in **Figure 1C**. Although some bottles under cork in the trial were a few milligrams per liter lower than the average, this was the only example of what may be described as sporadic bottle oxidation. From 4 to 10 months in the bottle, the wines under cork lost a further average 2.9 ± 0.8% total SO_2 (1.4 ± 0.9% for screwcaps), whereas from 10 to 23 months cork (2.6 ± 1.9%) and screwcap (2.6 ± 1.3%) wines recorded the same drop in total SO_2 to reach the values given in **Table 1**. During the 10−23 month period, the decline in SO_2 is no longer expected to be due to oxygen present at bottling, but rather to a similar small ingress of oxygen past the liner of the screwcap or through the cork closure.

Losses of free SO_2 followed a similar trend (**Figure 2**), with a large decrease over the first 4 months of 48 ± 5% on average for corks (versus 28 ± 5% for screwcaps) due largely to oxygen present at bottling. After this time, the decreases were similar with a further 14 ± 4% loss from 4 to 10 months for corks (versus 15 ± 10% for screwcaps) and 15 ± 4% from 10 to 23 months for corks (versus 14 ± 4% for screwcaps). Some bottles fell below 10 mg/L after 23 months, which may be of concern for continued aging of these wines. We can again conclude that with cork and screwcap the rate of ingress of oxygen into the bottle during storage was small. This is consistent with recent reports that the oxygen permeability of the best corks is of a similarly low value to that of screwcaps of <0.001 mL of oxygen per day (*17*). The role of this low level of oxygen in wine development in the bottle is still a matter of some debate.

Sauvignon Blanc wine contains a number of volatile thiols, present at very low concentrations, which are nevertheless

Table 2. Levels of Volatile Thiols, Visible Absorbance at 420 nm, and Levels of Polyphenols Analyzed by HPLC after 2 Years for Three of the Wine Treatments ($n = 3$)[a]

wine treatment	3, screwcap	11, screwcap	12, cork
initial free SO_2, mg/L	20	30	30
free SO_2 at 23 months, mg/L	10.8 (±0.5)a	14.0 (±0)a	12.3 (±3.3)a
3MHA, ng/L	117 (±9)a	122 (±14)a	93 (±11)a
3MH, ng/L	2188 (±109)a	2270 (±98)a	1873 (±81)b
visible absorbance at 420 nm	0.079 (±0.001)a	0.076 (±0.001)a	0.077 (±0.003)a
epicatechin, mg/L	5.8 (±0.2)a	6.6 (±0.1)b	6.6 (±0.1)b
caftaric acid, mg/L (CAE)	16.9 (±0.1)a	17.6 (±0.1)b	17.5 (±0.1)b
S-glut-caftaric acid, mg/L (CAE)[b]	7.6 (±1.1)a	6.1 (±0.1)a	6.2 (±0.1)a

[a] Standard deviations are given in parentheses after each value. Values followed by different letters are statistically different (ANOVA, Fisher's $LSD_{0.05}$). [b] CAE = caffeic acid equivalents.

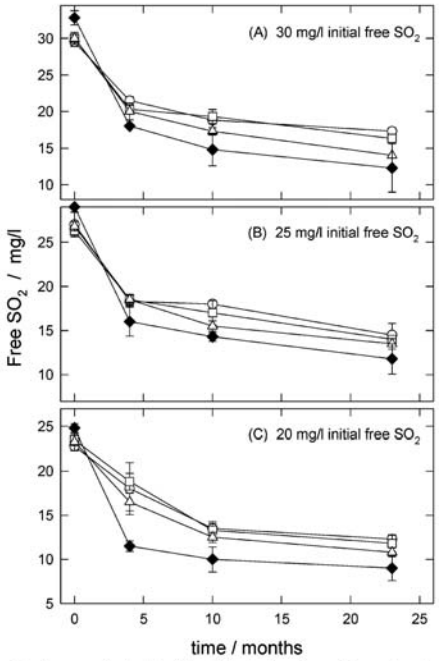

Figure 2. Decrease in levels of free SO_2 for Sauvignon Blanc wines bottled initially with (**A**) 30 mg/L free SO_2, (**B**) 20 mg/L free SO_2, and (**C**) 20 mg/L free SO_2: (○) screwcaps, 20 mm fill height; (□) screwcaps, 25 mm fill height; (△) screwcaps, 30 mm fill height; (◆) corks, 10 mm fill height ($n = 4$). Error bars are given for the standard deviation in each value.

responsible for a number of distinctive varietal aromas (8). These include 3MHA, giving a box tree or passion fruit aroma, and 3MH, giving a fruity, grapefruit aroma (*9*). Both of these thiols degrade with age in the bottle, particularly 3MHA, which also hydrolyzes to release 3MH (*8*), and via oxidation in the presence of polyphenols or when levels of protective SO_2 are low (*10*). The level of the volatile thiols 3MHA and 3MH after 2 years in the bottle for treatments 3, 11, and 12 are shown in **Table 2**. The levels of 3MHA and 3MH are well above the perception threshold for these components, being 4 ng/L for 3MHA and 60 ng/L for 3MH (*9*). The level of volatile thiols in the bottles with cork were 18−23% lower than for the screwcap bottles with the same initial level of SO_2. On the other hand, the difference between the two screwcap wines with different SO_2 levels was not statistically significant. The higher initial level of DO in the wines under cork may have contributed to the greater drop in 3MHA and 3MH, but the SO_2 data and results presented below for changes in levels of polyphenols and 420 nm absorbance do not indicate that oxidation was greater for the wine under cork. The possibility that the cork closure absorbed a certain percentage of 3MHA and 3MH during bottle storage needs to be considered here (*18*).

The visible absorbance at 420 nm and levels of catechol-containing polyphenols were quite similar across the three treatments tested (**Table 2**). Free caffeic acid, catechin, and flavonols such as quercetin and its glycosides were all below measurable levels. In particular, the screwcap- and cork-sealed wines with the same initial SO_2 level of 30 mg/L gave nearly identical results. The screwcap wine with the lower 20 mg/L initial free SO_2 gave a slightly higher 420 nm absorbance and was 4% lower in caftaric acid, lower in epicatechin, and, in two of the three wines tested, higher in *S*-glutathionyl caftaric acid. These indicators suggest that the level of SO_2 was more important for wine oxidation than the choice of cork or screwcap to seal the wines.

The sensory panel was first asked to evaluate whether pairs of wines were "different" or the "same". There was not a significant difference according to the *R*-index calculation. Although the panel identified different wines correctly 64% of the time, the answers were correct only 50% of the time when the wines were the same. Although a low test power is obtained by using only 12 assessors in the difference test, the lack of a significant difference between the treatments was supported by the following results of the descriptive analysis.

The average intensities of sensory descriptors for the three wines are presented in **Figure 3**. Aromas such as passion fruit associated with the volatile thiols 3MHA and 3MH were strong in the wines. The panelists also described the wines as containing citrus, stone fruit, and tomato vine characters, but they did not note a burnt or rubbery smell in any of the wines. Likewise, none of the wines sealed with cork were noted to be suffering from cork taint [which had been seen on occasions in other tastings of wines from this trial (*17*)]. On the other hand, the average intensities of the six sensory descriptors were very similar for the three wines (**Figure 3**), and in each case the statistical analysis produced p values >0.05. Differences between judges in the scale of intensities ascribed to the descriptors had lower p values. Once again, the small difference in levels of volatile thiols (**Table 2**) was not large enough to permit a sensory differentiation of the wines.

The PCA did not reveal any extreme values in the sensory or chemical data, whereas some grouping of the wine treatments was evident (**Figure 4**). The sensory descriptors (active variables) were dispersed around the four quadrants of the projection, whereas the first two principal components explained 58% of the variability in the model. Principal component 1

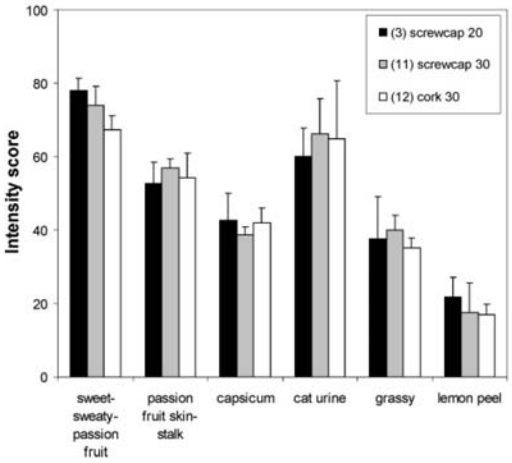

Figure 3. Intensity scores for six descriptors given by 12 panelists for three of the Sauvignon Blanc wine treatments: (black bars, 3) screwcap with 20 mg/L free SO_2; (gray bars, 11) screwcap with 30 mg/L free SO_2; (white bars, 12) cork with 30 mg/L free SO_2. Error bars are given for the standard deviation in each value.

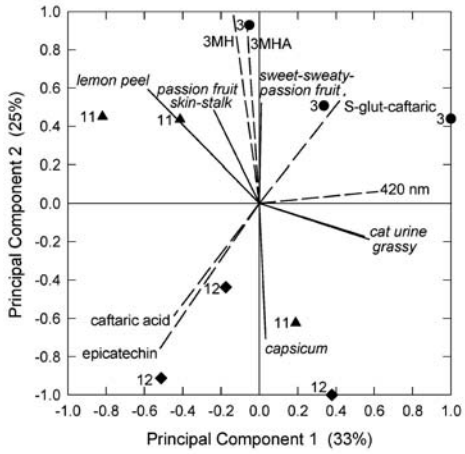

Figure 4. PCA biplot for the first two principal components for six sensory descriptors (solid lines) and six chemical measures (dashed lines) for nine individual Sauvignon Blanc wine bottles from three treatments: (3) screwcap with 20 mg/L free SO_2; (11) screwcap with 30 mg/L free SO_2; (12) cork with 30 mg/L free SO_2.

appears to comprise predominantly phenolic attributes, with caftaric acid and epicatechin showing covariance and correlating negatively with *S*-glutathionyl caftaric acid and with the absorbance at 420 nm to some extent. Grassy and cat urine sensory attributes also strongly covary and contribute to the first principal component. Levels of 3MHA and 3MH positively covary and load primarily on principal component 2. The sensory attributes of "sweet-sweaty-passion fruit" and "passion fruit skin-stalk" also correlate with levels of 3MHA and 3MH, whereas "capsicum" correlates negatively with all of these on the second principal component. Although levels of methoxypyrazines were not measured in this study, they are known to be particularly stable in wine (*19*), and significant differences in levels between these wines would not be expected. Hence, the negative correlation of capsicum with 3MHA and 3MH is likely to be due to the dampening of perceived capsicum with higher fruity aromas. Principal component 3 (not shown) accounts for 22% of the total variance and largely confirms the interpretation made above with the "sweet-sweaty passion fruit" vector correlating strongly with the 3MH and 3MHA attributes. However, the "passion fruit skin-stalk" vector loads 166° relative to the "sweet-sweaty passion fruit" vector in this component, implying a significant negative correlation.

The 20 mg/L free SO_2 screwcap wines (treatment 3) and the wines sealed under cork (treatment 12) tended toward opposite sides of the biplot (**Figure 4**). The lower levels of 3MHA and 3MH seen in wines under cork largely explains this trend. On the other hand, the influence of small levels of cork taint in lowering the perception of passion fruit related aromas, while not being perceived overtly as a cork taint, remains a possibility.

In conclusion, the extents of oxygen ingress, given by losses of SO_2, for wines bottled under cork and screwcap were shown to be very similar for the Sauvignon Blanc wine used in this trial. The difference between treatments in terms of the loss of SO_2 in the first 10 months after bottling appeared rather to be due to the differing exposure to oxygen at the time of bottling. Whereas the wines under cork and screwcap were not seen as different by a sensory panel, more of the volatile thiols 3MHA and 3MH were lost under cork than under screwcap (by 18−23%), and this loss could be due either to the absorption of aromas by cork or to wine oxidation.

In further trials we intend to follow the development of volatile thiols and other aroma compounds right from the time of bottling. Associations between sensory descriptors and chemical analyses will be extended to a wider range of Sauvignon Blanc wines. More work is also required to determine the optimal or minimum levels of SO_2 required to maintain varietal aromas in wines such as Sauvignon Blanc for an extended period of time.

ABBREVIATIONS USED

HPLC, high-pressure liquid chromatography; GC-MS, gas chromatography with mass spectrometer detection; DO, dissolved oxygen; 3MH, 3-mercaptohexan-1-ol; 3MHA, 3-mercaptohexyl acetate; ROTE, roll-on tamper-evident; TCA, trichloroanisoles; PVDC, polyvinylidene chloride; R_i, *R*-index values; *N*, number of decisions used to obtain the *R*-index; PCA, principal component analysis.

ACKNOWLEDGMENT

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Appendix D. NEW ZEALAND CONSUMER QUESTIONNAIRE FOR 2004 VINTAGE

Welcome to HortResearch

Wine Panel

HortResearch

Panellist Code: _____

Panellist Name: _____

Question # 1.

Gender:

- ❍ Male
- ❍ Female

Question # 2.

Age Group:

- ❍ 18-29 years old
- ❍ 30-39 years old
- ❍ 40-59 years old
- ❍ 60+ years old

Question # 3.

What nationality are you?

- ❍ NZ European
- ❍ NZ Maori
- ❍ Pacific Island
- ❍ Asian
- ❍ Australian
- ❍ European
- ❍ American
- ❍ Other
- ❍ Do not wish to answer this question

Question # 4.

Please describe:

_____

_____

_____

Question # 5.

Marital Status

- ❍ Single
- ❍ In a relationship living separately
- ❍ Couple living together
- ❍ Married
- ❍ Divorced
- ❍ Widowed

Question # 6.

Do you have dependent children living in your household?

- ❍ Yes
- ❍ No

Question # 7.

What is your highest level of education?

- ❍ None
- ❍ School certificate
- ❍ 6th form Certificate
- ❍ University entrance
- ❍ University entrance with bursary
- ❍ Trade/vocational certificate
- ❍ Diploma
- ❍ Bachelor degree
- ❍ Post graduate degree
- ❍ Other

Question # 8.

Please describe:

_____

_____

_____

Question # 9.

Combined annual household income (before taxes):

- ❍ <$25,000
- ❍ $25,001 - $50,000
- ❍ $50,001 - $75,000
- ❍ $75,001- $100,000
- ❍ $100,001 - $150,000
- ❍ Do not wish to answer

Question # 10.

How often do you drink wine?

- ❍ Once a day
- ❍ 3 - 4 times per week
- ❍ Once a week
- ❍ Once a month
- ❍ 2 - 3 times a year
- ❍ Once a year
- ❍ Never

Question # 11.

How often do you buy wine?

- ❍ Every day
- ❍ 3 - 4 times a week
- ❍ Once a week
- ❍ Once a month
- ❍ Once every six months
- ❍ Once a year
- ❍ Less than once a year
- ❍ Never

Question # 12.

How much wine do you normally buy at one time?

- ❍ One bottle
- ❍ 2 - 3 bottles
- ❍ 4 - 6 bottles
- ❍ 7 - 12 bottles
- ❍ More than 12 bottles
- ❍ I do not buy wine

Question # 13.

Where do you drink wine? (tick as many as appropriate)

- ❑ Home
- ❑ Friend's house
- ❑ Work
- ❑ At a Bar or Pub
- ❑ At a Restaurant
- ❑ Beach
- ❑ Recreational activities
- ❑ Other

Question # 14.

Please describe:

_____

_____

_____

Question # 15.

What time of day do you normally drink wine? (tick as many as appropriate)

- ❑ Brunch
- ❑ Lunch
- ❑ Afternoon
- ❑ After work/Uni
- ❑ Dinner
- ❑ Evening
- ❑ Other

Question # 16.

Please specify time of day:

_____

_____

_____

Question # 17.

How much do you normally spend on a bottle of wine (on average)?

- ❍ <$10
- ❍ $10 - $14
- ❍ $15 - $20
- ❍ $21 - $30

❍ $31 - $40
❍ $41 - $50
❍ >$50

Question # 18.

Which of the following white wines do you normally drink? (tick as many as appropriate)

❑ Chardonnay
❑ Sauvignon blanc
❑ Riesling
❑ Pinot Gris
❑ Gewurztraminer
❑ Sparkling
❑ White wine blend
❑ Other
❑ None

Question # 19.

Please specify:

_____

_____

_____

Question # 20.

Which of the following red wines do you normally drink? (tick as many as appropriate)

❑ Cabernet Sauvignon

- ❑ Merlot
- ❑ Pinot Noir
- ❑ Shiraz/Syrah
- ❑ Beaujolais
- ❑ Red wine blend
- ❑ Other
- ❑ None

Question # 21.

Please specify:

_____

_____

_____

Question # 22.

Do you normally drink red or white wine?

- ❍ Red
- ❍ White
- ❍ Neither
- ❍ Both

Question # 23.

Do you drink Sauvignon blanc.....

- ❍ Only in the summertime
- ❍ Year round
- ❍ Never

Question # 24.

Do you have a preference for wines from a specific country?

- ❍ Yes
- ❍ No

Question # 25.

If yes, which country do you prefer?

- ❍ New Zealand
- ❍ Australia
- ❍ France
- ❍ Spain
- ❍ Italy
- ❍ South America
- ❍ North America
- ❍ South Africa
- ❍ Other

Question # 26.

Please specify:

_____

_____

_____

Question # 27.

Which white wine style do you MOST PREFER? (Please tick only one)

- ❍ Chardonnay
- ❍ Sauvignon blanc
- ❍ Riesling
- ❍ Gewurtztraminer
- ❍ Pinot gris
- ❍ Sparkling
- ❍ White wine blend
- ❍ Other

Question # 28.

Please specify:

_____

_____

_____

Question # 29.

Which red wine style do MOST PREFER? (Please tick only one)

- ❍ Cabernet sauvignon
- ❍ Merlot
- ❍ Shiraz/Syrah
- ❍ Pinot noir
- ❍ Beaujolais
- ❍ Red wine blend
- ❍ Other

Question # 30.

Please specify:

_____

_____

_____

Question # 31.

When you purchase wine what influences you the most? Rank these where: Most important = 1 to Least important = 10

Rank	Concept
_____	Price
_____	Label
_____	Country of origin
_____	Type of wiine
_____	Brand
_____	Recommendation
_____	Re-purchasing for flavour
_____	Occasion (at home, as a gift, dinner at boss's home, etc)
_____	Season
_____	Other

Question # 32.

Please describe any other factors which influence you when purchasing wine:

_____

_____

_____

Question # 33 - Sample _____

Review Instructions

Place your wineglass on the tray, push it back through and shut the hatch.

While waiting for your next sample to come through, have a drink of water and a cracker to cleanse your palate.

Take the glass in your hand and swirl. Remove the watchglass and inhale the aroma then taste the sample and spit into the cup.
Mark on the scale below how much you like/dislike the wine.

Mark on the scale below how much you like/dislike the wine.

Overall Opinion

Dislike extremely	Dislike very much	Dislike moderately	Dislike slighty	Neither like or dislike	Like slightly	Like moderately	Like very much	Like extremely

You have finished now

Thank you!

Please go to the discussion room to collect your wine.

Appendix E. *R*-INDEX BALLOT

R Index **Code**_____

Name:_____

Direction: You are being presented 2 pairs of samples.
Smell each pair.
Circle whether they are the same or different.
Circle whether you are sure about your answer or unsure.

Please cleanse your palate between each sample.

Same Different

Sure Unsure

Appendix F. NEW ZEALAND SAUVIGNON BLANC: WHAT MAKES IT UNIQUE AND DO OREGON USA CONSUMERS LIKE IT?

Lund CM and Thompson M.
February 2007

New Zealand Sauvignon blanc: What makes it unique and do Oregon USA consumers like it?

Report to New Zealand Wine Growers

Lund CM and Thompson M. February 2007

The objective of this research was to determine what the consumer market in Oregon, USA, preferred in terms of Sauvignon blanc flavours. The research was conducted in two phases. Firstly, using the sensory evaluation skills of a trained and experienced taste panel, we sought to determine scientifically and map the flavour profile of 2005 vintage New Zealand, French, American, Chilean and Australian Sauvignon blanc. In the second phase, eight of the twenty seven wines considered were selected to assess the taste preferences of Oregon wine consumers.

Materials & Methods

Twenty seven commercially released Sauvignon blanc wines from France, USA, Australia, Chile, and New Zealand were selected for the flavour profile evaluation. New Zealand Sauvignon blanc was represented with wine selections from the three leading Sauvignon blanc growing regions: Marlborough, Wairarapa, and Hawke's Bay. With the exception of two of the French wines, where only the 2004 vintage was available, all the wines in this study were 2005 vintage.

Twelve trained panellists, each with over 250 hours of instruction and practice in Sauvignon blanc flavour assessment, evaluated the flavour profiles of the wines in this study. The twelve panellists evaluated each of the twenty seven wines in triplicate.

Reference standards used to identify and quantify seventeen varietal flavour attributes were: sweet-sweaty, passionfruit, capsicum, boxwood/cat's pee, passionfruit skin/stalk, grassy, flinty/mineral, citrus, bourbon, apple lolly/candy, tropical, mint, fresh asparagus, canned asparagus, stonefruit, apple, herbal floral, and honey mead.

After the sensory evaluation, eight wines representing the full product space were evaluated. One wine from each of France, USA, Chile, Hawke's Bay, Wairarapa and the three wines from Marlborough were selected for consumer assessment. Consumers, who simply rated their preferences amongst the wines, were recruited in Oregon on the basis of their being "wine consumers."

Results and Discussion

In Figure 1, we see that Marlborough Sauvignon blanc wines are noticeably distinctive in their predominance of capsicum, sweet-sweaty passionfruit, passionfruit skin, tropical, apple and stone fruit characteristics. The other wines have predominantly flinty/mineral, and bourbon flavour characteristics.

Figure 3 confirms that the character of Marlborough Sauvignon blanc wines (South Island) was significantly different from both the international and North Island wines in the 2005 vintage. The Chilean wines were the closest in character to Marlborough wines, but they lacked the fruitier notes.

Figure 3 reveals the overall liking mean scores recorded by the Oregon consumers in the study. Using Analysis of Variance (ANOVA), there are few significant differences in wine preferences. However, the Wairarapa and French Sauvignon blanc wines were greatly preferred over the Chilean and Hawke's Bay wines, which had the least amounts of green characteristics. The lower levels of green characteristics in Chilean and Hawke's Bay wine relative to Wairarapa and French wine was found during trained panel evaluations of sensory attributes: grassy, capsicum, passionfruit skin/stalk, mint, floral herb and fresh asparagus. The data suggest that Oregon consumers prefer green characteristics in Sauvignon blanc. Over half of these consumers normally drink wine once a week.

Table 1 and 2 shows the demographic information for the consumers in the study.

Figure 4 is a preference map, created by correlating trained panel data with consumer data. A cluster analysis identifying consumer clusters, and their desired product characteristics, is shown. There were three distinct consumer clusters 1(38%), 2(36%) 3(26%) from an external preference map analysis (Figure 4).

a. Cluster 1 were predominately females (69%), who liked a sweet sweaty passionfruit, tropical, passionfruit skin/stalk, apple style Sauvignon blanc and spent less on wine and were older than the other clusters.

b. Cluster 2 liked a flinty bourbon Sauvignon blanc style, were predominately women (61%), and had more people in higher income brackets, but were more infrequent drinkers and least likely to purchase Sauvignon blanc.

c. Cluster 3 had more Sauvignon blanc consumers did not like the apple lolly/candy, citrus, stonefruit, apple, mint style wine. They tended to

be younger, predominately male (68%) and spent more money on wine and made more money than Cluster 1.

To date, Californian-style Sauvignon blanc has been the main varietal influence for Oregon consumers. The 2004 and 2005 vintages of American Sauvignon blancs were assessed as high in grassy, apple lolly, citrus, and mint characteristics. The American wines contained green notes but not the tropical fruity notes found in the Marlborough wines.

Do Oregon consumers appreciate the flavour profile of Marlborough Sauvignon blanc?
This seems unlikely. While those surveyed were aware of Marlborough Sauvignon blanc, using the descriptors 'clean, herbaceous, mineral, flinty, green, stalky,' very few of them stated that Marlborough Sauvignon blanc exhibited both fruity and green characteristics.

Do Oregon consumers like New Zealand Sauvignon blanc?
The 2004 study presented at the ICCS in Christchurch found that New Zealand wine consumers clearly preferred New Zealand Sauvignon blanc to similar French, Australia and South African wines. Oregon consumers do not share the same high preference (Lund 2006). While Oregon consumers like Sauvignon blanc, they do not appear to have a distinct preference. In fact, a third of consumers in this study only drink Sauvignon blanc in the summer, whereas only 17% New Zealand wine consumers drank Sauvignon blanc in the summer.

Recommendation

The Oregon consumers polled in this study regard New Zealand Sauvignon blanc as a high quality wine, but in the blind tasting this was not necessarily reflected in their scores. An educational marketing campaign may need to address this discrepancy between expectations and perceptions. An educational marketing campaign could give American consumers an understanding of New Zealand Sauvignon blanc. Studies have linked consumer sensory perception expectation with consumer product image as important for the success of the product purchase (Backstrom & Johansson 2006).

Appendix

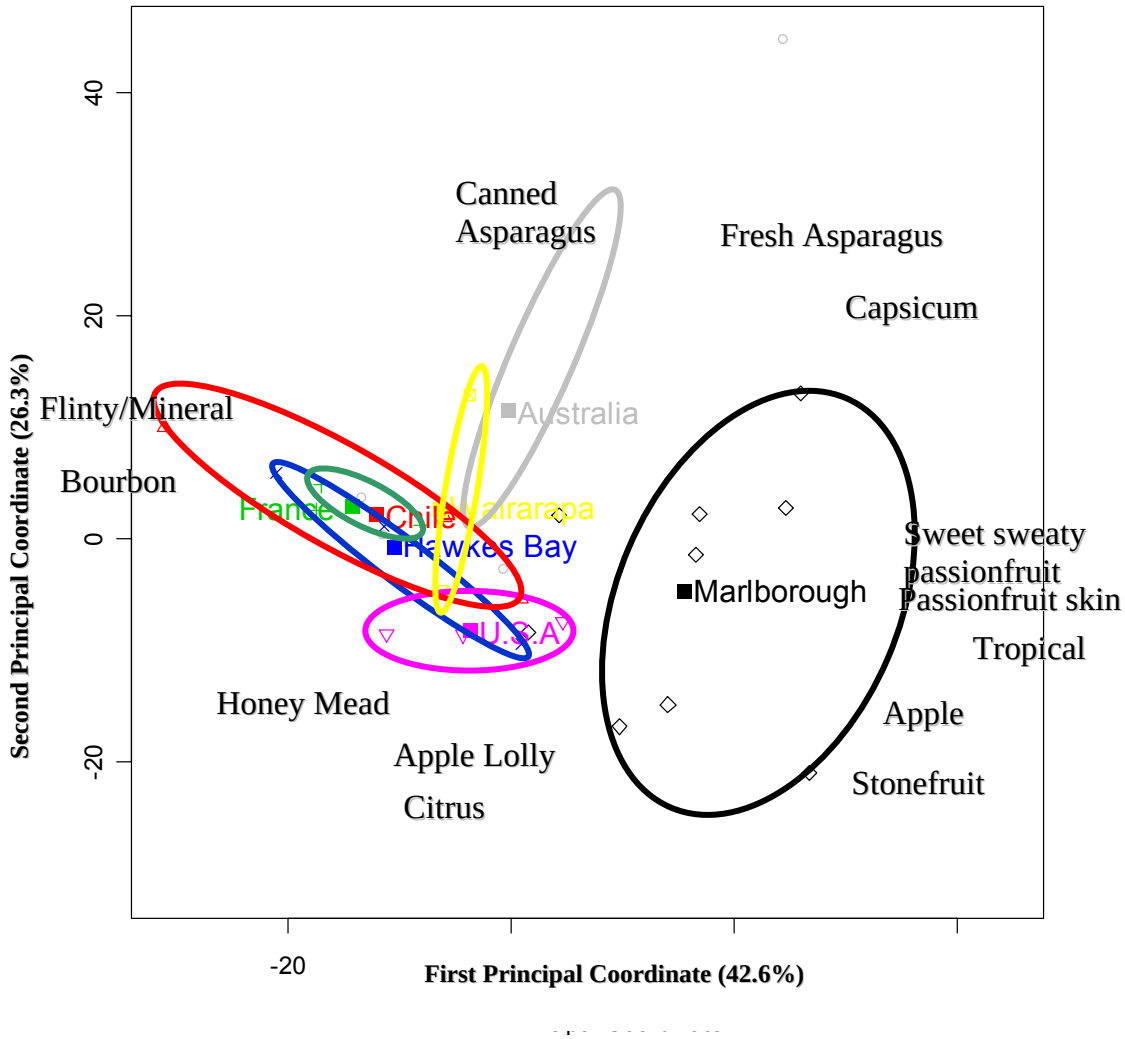

Figure 1. Principal component analysis using the first and second principal components to explain 2005 ratings of Sauvignon blanc wines from five countries.

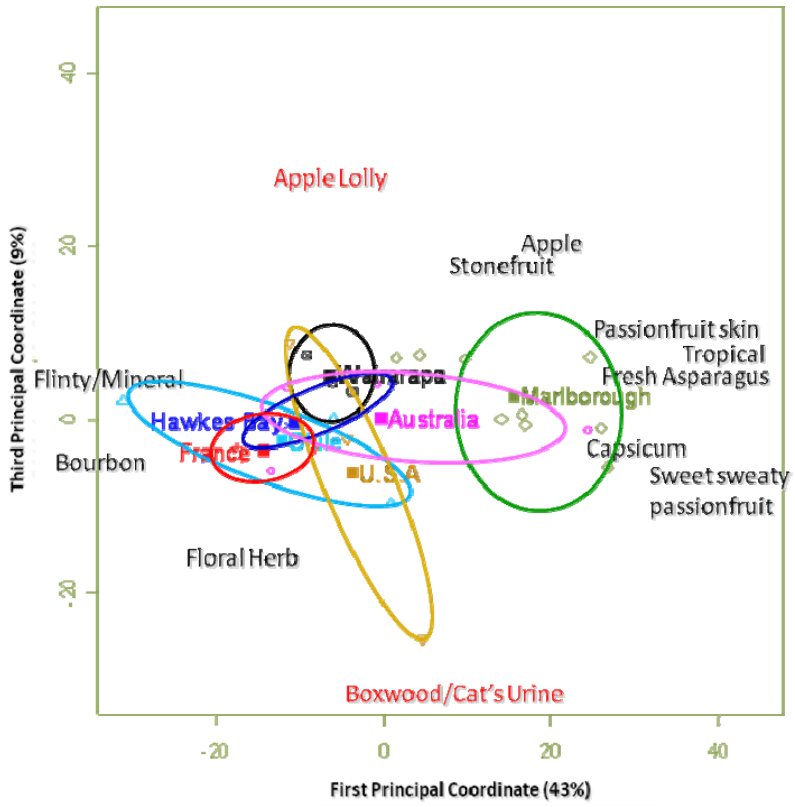

Figure 2. Principal component analysis using the first and third principal components to explain 2005 ratings of Sauvignon blanc wines from five countries.

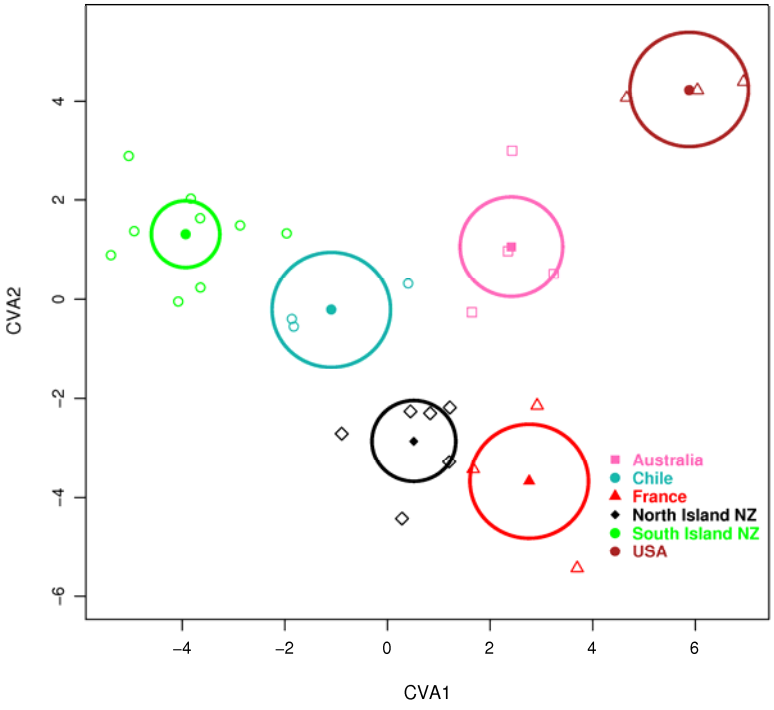

Figure 3. Canonical Variate Analysis of 2005 Sauvignon blanc wines from five countries.

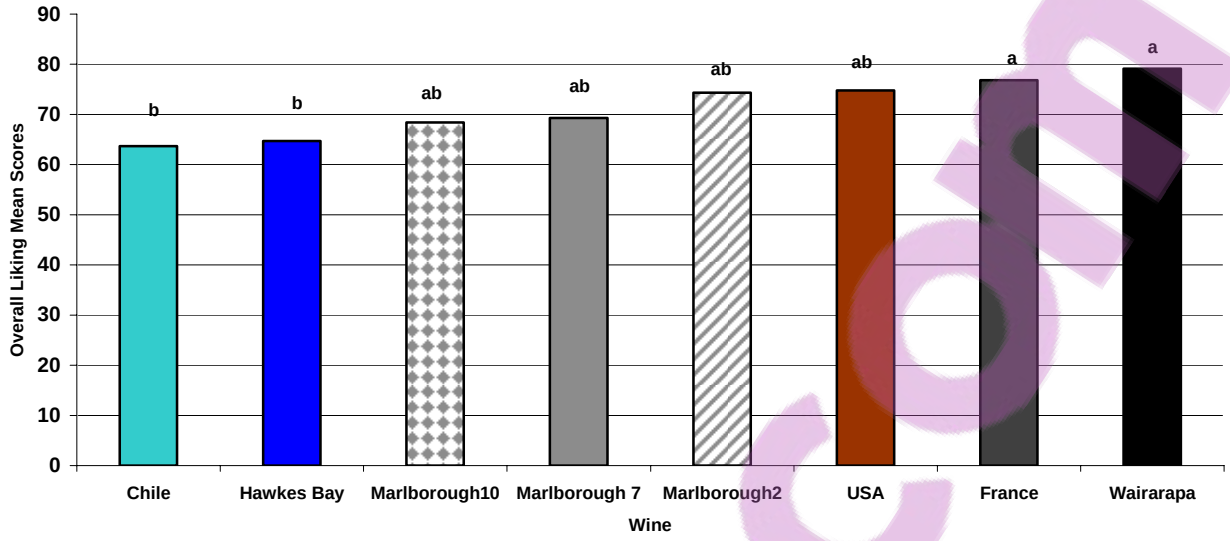

Figure 3. Overall liking mean scores of American consumers comparing eight Sauvignon blanc wines. Bars with different letters are significantly different from one another (P<0.05).

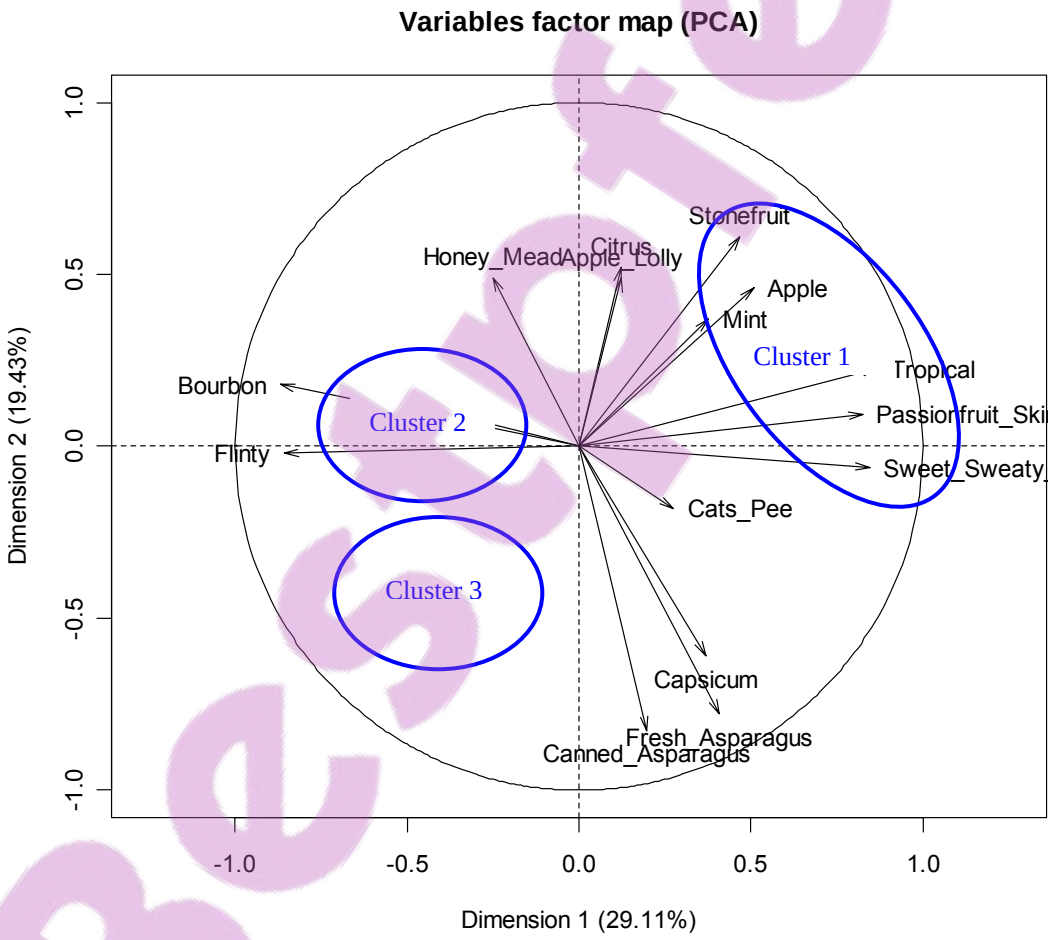

Figure 4. Cluster analysis of American consumer preferences for seventeen Sauvignon blanc attributes.

Table 1. Demographic information from the Oregon USA consumer panel (N=85).

Demographic	Percentage
Gender	
Female	44%
Male	56%
Age	
18-24 years	6%
25-34 years	27%
35-44 years	15%
45-54 years	26%
> 55 years	26%
Status	
Single	13%
In a relationship	2%
Couple living together	15%
Married	61%
Divorced	5%
Separated	2%
Widowed	2%
Frequency of wine consumption	
Once a day	5%
3-4 times a week	29%
Once a week	53%
Once a month	12%
Once a year	1%
Never	0%
Income	
<US$25,000	13%
US$25,001 to US$50,000	32%
US$50,001 to US$75,000	25%
US$75,001 to US$100,000	8%
US$100,001 to US$150,000	12%
>US$150,000	4%
Do not wish to answer	7%
Ethnicity	
USA	92%
African	2%
Canadian	1%
South American	1%
European, Asian, Australian, New Zealander	0%
Other	3%
Do not wish to answer	0%

Table 2. Demographic information from the Oregon USA consumer panel (N=85).

Wine	Percentage
Wine preference for red or white wine	
White	25%
Red	29%
Both	46%
Neither	0%
White wine varietal preferences	
Sauvignon blanc	6%
Pinot gris	29%
Riesling	25%
Chardonnay	25%
Sparkling	6%
White wine blend	4%
Gewurztraminer	0%
Other	5%
Time of day for Sauvignon blanc wine consumption	
Brunch	0%
Lunch	0%
After work/school	6%
Dinner	40%
Evening	53%
Other	1%
Place for Sauvignon blanc wine consumption	
Home	95%
Restaurant	86%
Friend's	84%
While participating in recreational activities	13%
A bar/pub	9%
Beach	8%
Work	1%
Average price spent on a bottle of wine	
< US$7	13%
US$7 to US$11	53%
US$11 to US$15	24%
US$15 to US$20	8%
US$20 to US$25	2%

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Appendix G: PRELIMINARY EXPERIMENT TO CHAPTER 2

INTRODUCTION

This was a preliminary experiment to examine the influence of the panel leader on the motivation of trained panellists. This was one of the initial experiments conducted and though it requires a greater sample size for validity. I thought it might aid the examiners in understanding how an initial study was conducted.

Objective

How did the use of verbal cues by panel leaders affect panellist performance?

MATERIALS AND METHODS

Experiment 1 - Effect of panel leader's verbal cues

Trained panel

Twelve trained panellists were used to research the effect of verbal cues from the panel leader. These panellists assessed Sauvignon blanc wine using previously established terminology and references (Lund et al., 2009) and traditional sensory methodology (Lawless and Heymann, 1999). The panellists in this experiment were recruited specifically for their inexperience as trained panellists. For this experiment, the panel underwent ten one-hour training sessions, over a period of a month plus three assessment sessions. Panellists were asked to rate their self-confidence before and after each training session on a 150-mm linescale, where the range was from no self-confidence to extreme self-confidence.

Methodology to measure performance

Panellists' threshold levels for MIBP were determined using the *R* index difference test methodology (Bi and O'Mahony, 1995). Five repetitions of five different levels of MIBP (0.25, 0.50, 1.00, 2.00, 4.00 ng/L water) were given as coded samples in a balanced design for each of the five repetitions, which yielded a total of 25 samples. The panellists were asked whether the sample was "different" or the "same" as the sample of water (reference sample), and if their judgment was "sure" or "unsure". *R*-index values (R_i) were calculated, and R_i – 50% results were compared with the critical value for a one-tailed test at a level of significance of 5% that the result is greater than chance (Bi and O'Mahony, 1995; Cliff et al., 2000).

The data collection was performed in booths with daylight lighting at the HortResearch Sensory and Consumer Science Facility in Mt Albert, Auckland, New Zealand. A positive airflow was maintained in the booths to reduce any odours not associated with the wine. Three-digit codes were put on the wine glasses to remove any identification of samples.

Negative and positive verbal cues

The panellists were randomly divided into Group 1 and 2 for the experiment, with six panellists in each group contributing to two sessions of data collection. In the first session, Group 1 was given a briefing with positive verbal cues as follows:

> Welcome and thanks for participating in this wine study. You all have been doing such an incredible job at coming up to speed in the evaluation of wine. Your scores are great and the way you are nailing the references has been right on track even more quickly than I expected. There are 8 pairs of samples that I need you to determine if they are the same or different. This test should be very simple just like the test you did last Friday. Your results from that test were great and I am sure you will find this one equally simple. I know you guys will do an excellent job as you always do. You can take as much time as you need. You guys are great. Thanks so much for all your hard work. Are there any questions?

In the first session, Group 2 was given a briefing with negative verbal cues as follows:

> Welcome and thanks for participating in my study. I understand that you are new to evaluating wine. There are 8 pairs of samples that I would like to determine if they are the same or different. There are few differences among the wine so you will find this test very difficult. I understand that you are a new panel and aren't adequately trained, but please attempt this task. You can take as long as you need, as I know it will be extremely hard for you to determine the differences. Thank you. Are there any questions?

In the second session, Group 1 was given a briefing with negative verbal cues as follows:

> Welcome and thanks for participating in my study. I understand that you are new to evaluating wine. Your results on Cynthia's test yesterday weren't very good but I need you to look at my samples anyway. There are 8 pairs of wine

that you need to determine if they are the same or different. Please understand that the differences are small so this test will be extremely difficult. I understand that you are a new panel and aren't adequately trained, but please attempt this task. You can take as long as you need, as I know it will be hard for you. Thank you. Are there any questions?

In the second session, Group 2 was given a briefing with positive verbal cues as follows:

> Today you are doing a second part of my study. You all have been doing such an incredible job at coming up to speed in the evaluation of wine. Your scores are great and the way you are nailing the references has been right on track even faster than I expected. There are 8 pairs of samples that I need you to determine if they are the same or different. This test should be very simple just like the test you did yesterday for Rachel. Your results from that test were very accurate and I am sure you will find this one equally simple. I know you guys will do an excellent job as you always do. You can take as long or as short as you need. You guys are great. Thanks so much for all your hard work. Are there any questions?

The panellists assessed the 1 ng/L MIBP solution (A) and water (B) with an R-index difference test. Coded samples were presented in a balanced design of pairs for each of the four possible combinations of wines in two replications (AA, AB, BA, BB). The panellists followed the same R index methodology as stated above in the threshold determination.

RESULTS

Experiment 1 - Effect of panel leader's positive and negative verbal cues

Panellists' perceived confidence measurement

All but one of the twelve panellists felt more confident after the training session than before the training session, but this was only statistically significant for Panellists 3 and 4. There was a great degree of variability in the mean scores, as confidences fluctuated significantly during the training process (Figure 2.2). Panellist 11 had the greatest variability and the lowest average perceived confidence rating. Panellist 12 was the only panellist that had a lower score after training. This panellist participated in fewer panel sessions than any other panellist did, so perhaps they felt they were

not at the same performance level as the other panellists on certain days, which caused them to rate their perceived confidence lower.

Figure 2.2 shows that the panellists had an overall positive experience while being trained but that panellists' confidence fluctuated as a result of the challenges in learning a new skill.

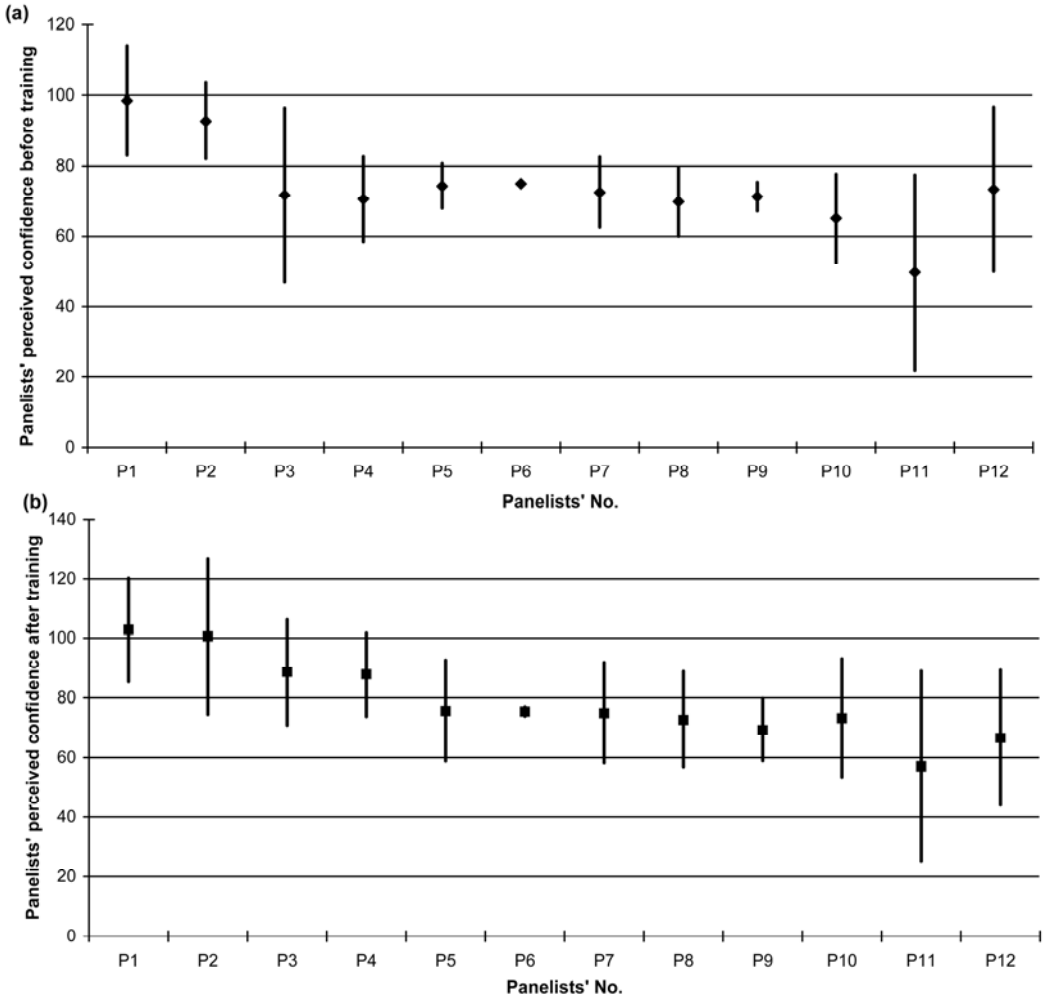

Figure G.1. Twelve panellist rated mean scores (n=10 sessions) for their perceived confidence before and after each of the ten training session. Error bars = Standard error of difference.

Panellists' ability/competence measurement

Results from the panel threshold levels listed in Table G.1, and show that five panellists could perceive very low amounts of MIBP (up to 0.25 ng/L), whereas three other panellists (panellists numbers 9, 10, and 11) had significantly higher perception thresholds, at 2 ng/L ($P \leq 0.05$). The average threshold of the panel was at 1 ng/L,

which is below the 2 ng/L threshold for MIBP reported in the literature (Buttery et al., 1969).

Table G.1. Probability of correct answers according to R-index analysis for the detection threshold testing of MIBP for twelve panellists.

	MIBP Concentration					Threshold Level
Panellist	**0.25 ng/L**	**0.5 ng/L**	**1 ng/L**	**2 ng/L**	**4 ng/L**	**MIBP ng /L**
P10	0.38	0.3	0.737	1	1	2.0
P11	0.74	0.6	0.72	0.98	1	2.0
P9	0.54	0.54	0.78	0.96	1	2.0
P6	0.62	0.78	0.84	0.94	1	1.0
P1	0.62	0.34	0.9	0.9	0.9	1.0
P7	0.74	0.74	0.86	0.9	0.6	1.0
P4	0.5	0.44	0.9	0.9	0.9	1.0
P5	0.82	0.84	0.98	0.76	0.88	0.25
P12	0.86	0.88	0.8	0.9	0.9	0.25
P2	0.9	0.9	0.84	0.9	0.9	0.25
P8	0.9	0.9	0.9	0.9	0.9	0.25
P3	0.94	0.88	0.94	1	1	0.25
Average Panel *R*-Index Value	**0.713**	**0.678**	**0.850**	**0.920**	**0.915**	
***R*-Index Critical**	**0.818**	**0.818**	**0.818**	**0.818**	**0.818**	

Panellists' perceived confidence and ability after positive and negative verbal cues from panel leader

Figure G.2 reveals a great amount of variability in panellists' perceived confidence scores following both the negative (de-motivation) and the positive (motivation) verbal cue briefing sessions.

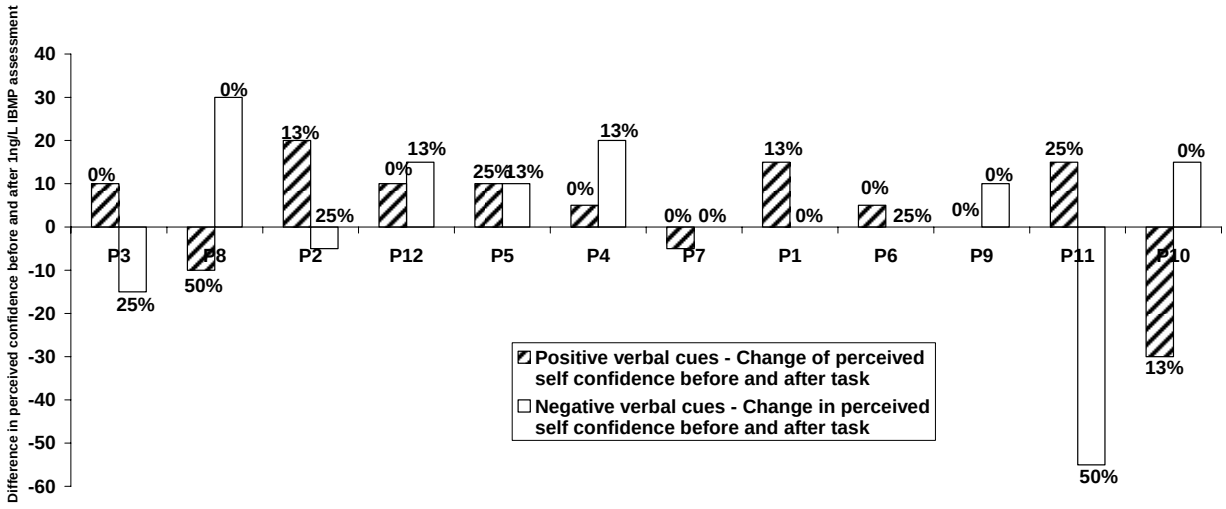

Figure G.2. Comparison of difference in sensory panellists' perceived confidence scores before and after sessions with negative and positive cues from the panel leader. Percentages with each bar indicate percentages of incorrect answers.

To improve understanding, the percentage of incorrect answers and perceived confidence scores of the top- and the bottom-performing panellists were examined more closely. The three top-performing panellist (P3, P8 and P2) had lower detection thresholds (0.25 ng/L MIBP) than those required to successfully perceive the concentrations used in the experiment (1 ng/L MIBP). Neither the negative nor the positive cues of the panel leader appeared to affect these three panellists (Figure G.2). However, the panellists were consistent in rating their perceived confidence in direct correlation to their performance. This findings are supported in the sports literature, which showed that having personal standards can prevent athletes from experiencing debilitating anxiety while carrying out a task, thereby enhancing their performance (Stoeber et al., 2007). These top-performing panellists may have set similar personal standards; allowing their performance to influence their confidence despite external cues.

Three panellists (P9, P10, and P11) had detection thresholds (2 ng/L MIBP) higher than the thresholds required to successfully perceive the concentrations used in the experiment (1 ng/L MIBP). Panellist 11 showed the most dramatic difference in confidence scores after receiving verbal cues. Overall, this panellist had the highest number of incorrect answers in the group and their confidence was clearly influenced

by the verbal cues. Following the negative verbal cues, Panellist 11, with 50 % incorrect answers, performed poorly on the test. The de-motivation briefing also clearly affected their perceived confidence score which decreased by 50-pt. Panellist 11 showed no change in their performance after receiving positive verbal cues, although their perceived confidence score increased. Hanton, et al. (2004) showed that in the absence of self-confidence, elite athletes found anxiety to have a debilitating effect whereas in the presence of high self-confidence athletes viewed competitive anxiety as positive and facilitative. His findings showed that self-confidence is essential in warding off debilitating thoughts that can have negative effects on performance.

Panellist 10 also had interesting patterns in their confidence ratings, but quite opposite to those of Panellist 11. This panellist's confidence decreased after receiving the motivating briefing. The education literature explains that a student can experience a decreased confidence when they feel their ability does not match the ability of their peers. This indicates the importance of perceived ability in motivating performance (Cole et al., 2004).

The third panellist (Panellist 9) with high thresholds was probably just having an "off day" during the threshold determination session and produced scores that were atypical for them on that particular day. In subsequent sessions, Panellist 9 had no incorrect answers and their confidence scores were fairly constant.

The affect of the panel leader's negative/positive verbal cues on this new panel had no dominant effect. While the small number of panellists was a limitation of this experiment (trained panel is typically limited to groups of 8-12 panellists), giving negative cues introduced a risk of inhibiting the panel's performance. The researchers hoped to minimise this potential risks of an ineffective panel by limiting the experiment to one panel. Despite the sample size, the findings do give some insight into the effects of verbal cues and appropriate levels of challenge.

DISCUSSION

Positive and negative cues from the panel leader can affect certain panellists but will probably have a stronger influence on panellists with lower levels of intrinsic motivation. Previous research showed that when experienced panellists were given negative verbal cues, they responded positively, perceiving the negative feedback as

a challenge, which in turn improved their competency and their performance levels (Lund, 2005). If a panellist lacks competency, as demonstrated by Panellist 11, negative cues from the panel leader are more likely to have a negative impact and lead to poor performance.

The panel leader needs to be aware of appropriate levels of challenge. Reinboth, et al. (2004) confirmed that when a coach provided a training environment of autonomy and relatedness, and introduced challenge, this combination improved both the athlete's performance as well as the athlete's perceptions of their own competence.

FUTURE RESEARCH

In the trained panel experiment 1, the briefings failed to produce a uniform effect on all panellists. However, this response variability could be managed by the panel leader, using a screening questionnaire to assess what motivational factors influence individual panellists. With a comprehensive understanding of motivational factors the panel leader could tailor their approach for each panellist. Good panel leaders probably adapt their responses intuitively, but improving and defining this process could assist all panel leaders.

Future research should evaluate other research disciplines, such as the psychology, sports psychology and education research, that have looked into maximizing and gaining better insight into motivation of people to perform a task. Understanding what motivates people to perform a task, may aid sensory panel research through better engagement in the training. Measuring how motivated panellists are would be the initial step. Understanding how performance relates to performance would be a secondary step.

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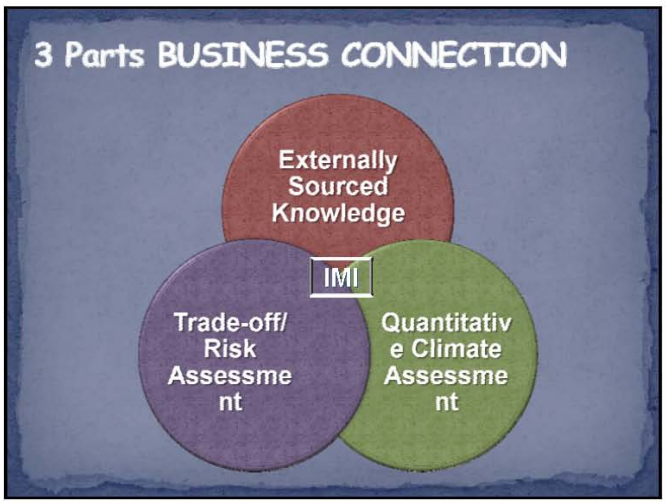
Appendix H: SAUVIGNON BLANC TRAINED PANEL'S THRESHOLD DATA PRESENTED AT WINE SCIENCE REVIEW OF THE NEW ZEALAND SAUVIGNON BLANC PROGRAMME (OCTOBER 30 - NOV 1, 2007)

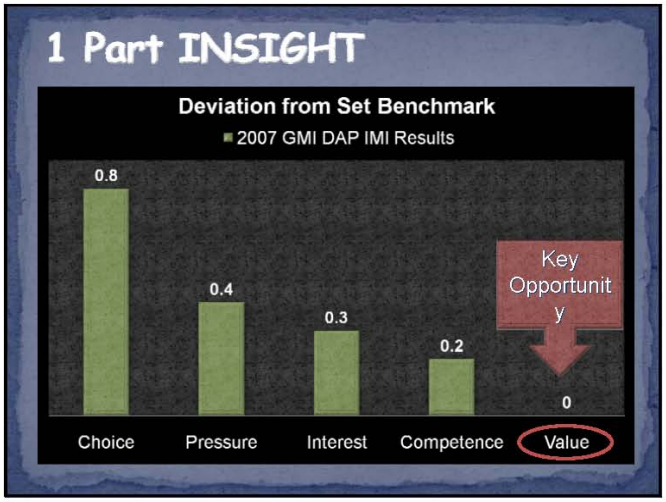
Aroma Compounds	Panel's thresholds in water (ng/L)	
	Detection Threshold	Recognition Threshold
Isobutyl methoxypyrazine (MIBP)	1	125
4-mercapto-4-pentanone (4MMP)	18	125
3-mercaptohexanol (3MH)	23	125
3-mercaptohexyl acetate (3MHA)	6.5	250

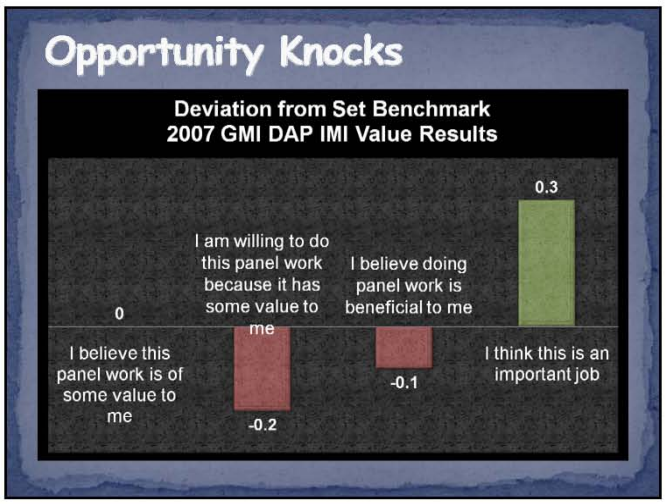
Appendix I: SOCIETY OF SENSORY PROFESSIONAL PRESENTATION OF APPLYING THE RESEARCH FROM THIS THESIS BY ANOTHER SENSORY PROFESSIONAL

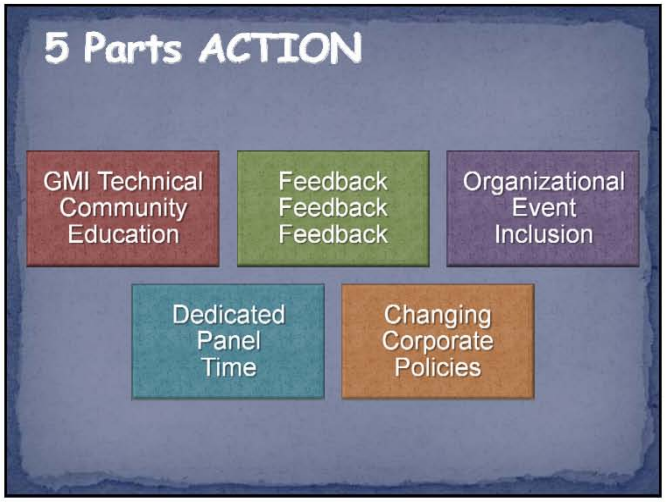

1 Part ENLIGHTENMENT
We Need the IMI
53% at Risk

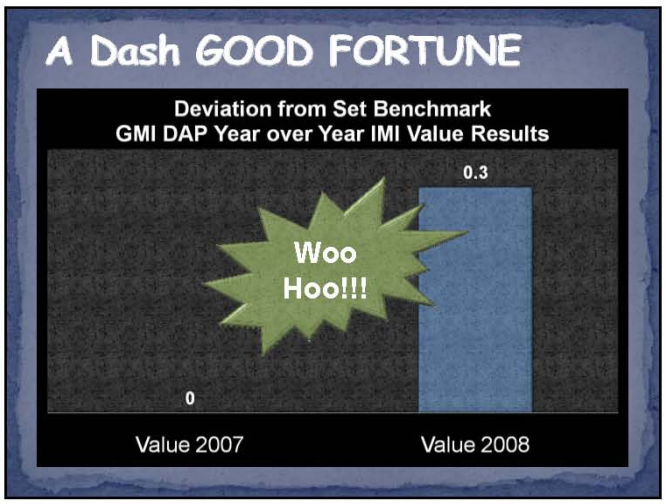

2 Parts COLLABORATION
Yea, we have more data for our research!!!
Yea, we can measure panel motivation!!!

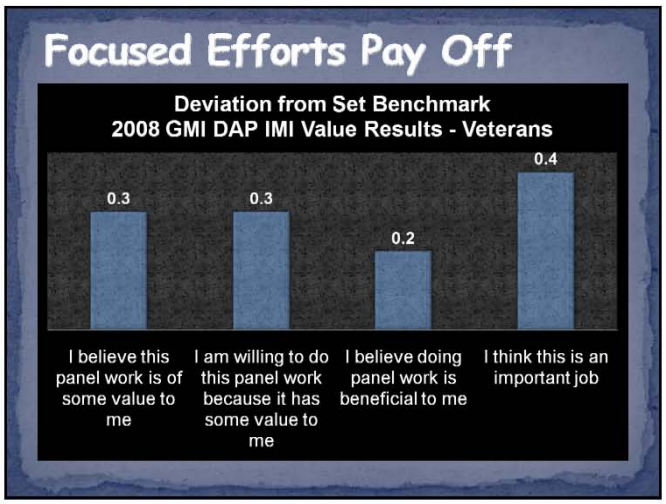

3 Parts BUSINESS CONNECTION
Externally Sourced Knowledge
IMI
Trade-off/ Risk Assessme nt
Quantitativ e Climate Assessme nt

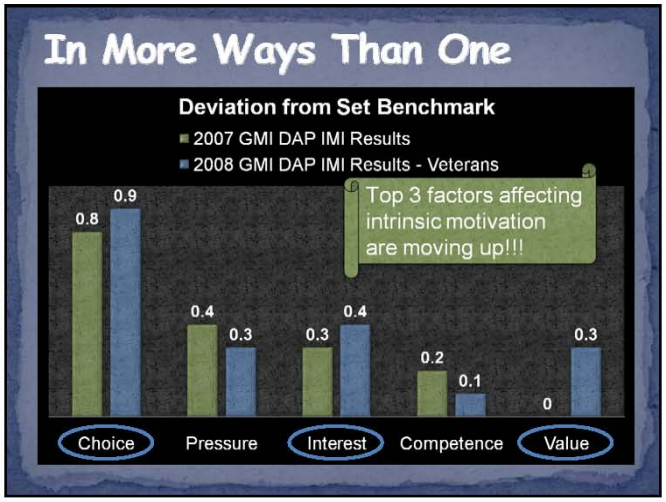

1 Part INSIGHT
Deviation from Set Benchmark
2007 GMI DAP IMI Results
0.8
0.4
0.3
0.2
0
Key Opportunit y
Choice
Pressure
Interest
Competence
Value

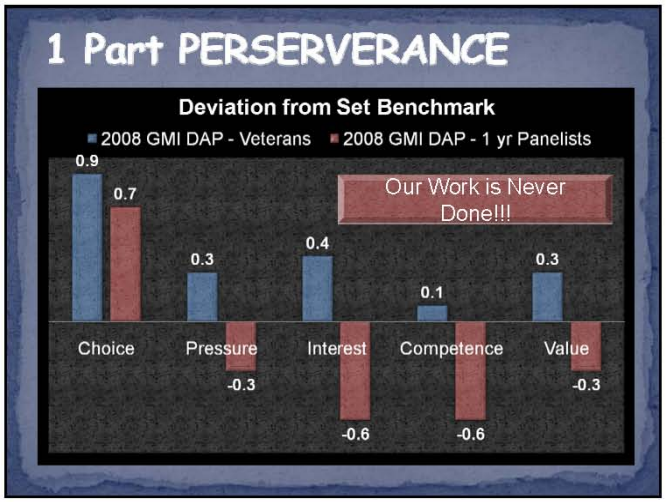

Opportunity Knocks
Deviation from Set Benchmark
2007 GMI DAP IMI Value Results
0
I believe this panel work is of some value to me
I am willing to do this panel work because it has some value to me
-0.2
I believe doing panel work is beneficial to me
-0.1
0.3
I think this is an important job

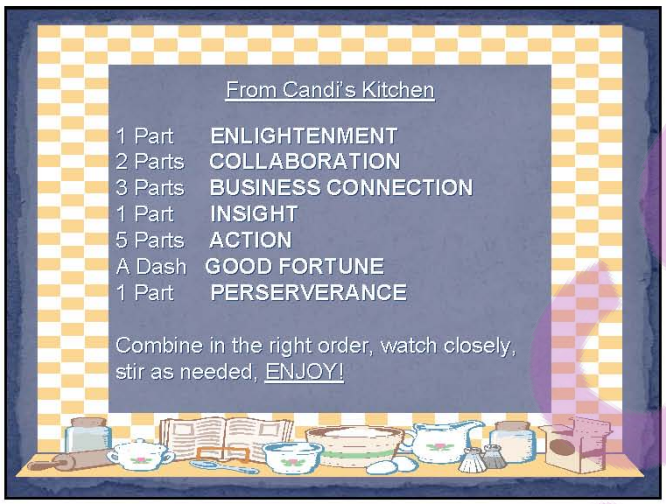

5 Parts ACTION
GMI Technical Community Education
Feedback Feedback Feedback
Organizational Event Inclusion
Dedicated Panel Time
Changing Corporate Policies


A Dash GOOD FORTUNE
Deviation from Set Benchmark
GMI DAP Year over Year IMI Value Results
0.3
Woo Hoo!!!
0
Value 2007
Value 2008


Focused Efforts Pay Off
Deviation from Set Benchmark
2008 GMI DAP IMI Value Results - Veterans
0.3
0.3
0.2
0.4
I believe this panel work is of some value to me
I am willing to do this panel work because it has some value to me
I believe doing panel work is beneficial to me
I think this is an important job


In More Ways Than One
Deviation from Set Benchmark
2007 GMI DAP IMI Results
2008 GMI DAP IMI Results - Veterans
Top 3 factors affecting intrinsic motivation are moving up!!!
0.8
0.9
0.4
0.3
0.3
0.4
0.2
0.1
0
0.3
Choice
Pressure
Interest
Competence
Value


1 Part PERSERVERANCE
Deviation from Set Benchmark
2008 GMI DAP - Veterans
2008 GMI DAP - 1 yr Panelists
Our Work is Never Done!!!
0.9
0.7
0.3
-0.3
0.4
-0.6
0.1
-0.6
0.3
-0.3
Choice
Pressure
Interest
Competence
Value


From Candi's Kitchen
1 Part ENLIGHTENMENT
2 Parts COLLABORATION
3 Parts BUSINESS CONNECTION
1 Part INSIGHT
5 Parts ACTION
A Dash GOOD FORTUNE
1 Part PERSERVERANCE
Combine in the right order, watch closely, stir as needed, ENJOY!

Appendix J: PUBLICATION OF CHAPTER 2

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Effects and influences of motivation on trained panelists

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ABSTRACT

Trained panelist motivation is an important factor to consider in sensory evaluation. While psychology, education and sport science fields have researched motivation extensively, knowledge about panelist motivation within sensory science is limited. However, findings from existing research in these other areas can be applied.

This research investigated the factors that affect and influence panelists' motivation. The first survey ($n = 74$) revealed that extra income and a general interest in food were the key drivers in inspiring people to become panelists, whilst enjoyment in being a panelist, interest in food and extra income were key drivers for people to remain panelists. In a second survey ($n = 108$), the intrinsic motivation of panelists from four countries was assessed. External panels were found to be more intrinsically motivated than internal panels. The experience level of the panelists also plays a role in their intrinsic motivation.

1. Introduction

Sensory scientists control external factors such as noise in the booths, external odours and lighting in order to reduce bias in the data collection process (Lawless & Heymann, 1999). The reduction of extraneous audio and visual distraction allows panelists to focus on the product being evaluated, reducing external bias, and improving the accuracy of the data. In addition to controlling physical factors, sensory scientists also consider the control of psychological factors. As human beings, panelists are affected by certain psychological influences, including stimulus error, habituation error, logical error, and contrast error (Meilgaard, Civille, & Carr, 2007). Sensory scientists are aware of these influences and attempt to minimize their psychological effects through the presentation of samples in randomized order, limiting the amount of information panelists receive regarding the samples, and performing tests in double-blind situations (Lund et al., in press).

One psychological factor that has been determined to have an effect on performance is panelist motivation. Sensory scientists have been trained to regard panelists' motivation as crucial to the success of the panel, and have found that an interested panel is more effective than a disinterested panel (Meilgaard et al., 2007). More recently, Moskowitz, Munoz, and Gacula (2005) stated that the panel leader plays a critical role in maintaining panelists' motivation. Word and Gress (1980) suggested exploring the effect on motivation in response to different reward systems, such as telling panelists they have performed well, giving them a certificate, or monetarily rewarding them. Several researchers examined whether feedback motivates the panelists to perform better (Armstrong, McIlveen, McDowell, & Blair, 1996; Marchisano, Vallis, & Macfie, 2000). Marchisano et al. (2000) found that giving panelists feedback in a recognition or identification test had a positive effect on performance, whereas feedback on triangle tests showed no effect, and feedback in a scaling test had a negative effect. Findlay, Castura, Schlich, and Lesschaeve (2006) used computerized feedback, not to motivate, but to shorten training time. Most of this literature was mainly speculative. Aside from considering the effects of performance feedback, none of the research considered the role of feedback in relationship to the motivation of panelists, and how that improved motivation impacts the quality of panel data. The current study was guided from other research disciplines in psychology, sports training, and education literature, particularly when applicable to the concepts of trained panelists' motivation.

Psychology literature indicates that sizable amounts of confidence and motivation lead to improved performance. Deci and Ryan (1985,2000) presented a self-determination theory that has been generally accepted in psychology and sports psychology research. That theory uses motivation orientation to explain the degree of self-determined behaviour regulation, and maintains that the self-regulating nature of intrinsic motivation leads to consistently high levels of performance behaviour. The opposite behaviour would be amotivation (lack of motivation). Extrinsic motivation lies between these two extremes. Extrinsic motivation occurs when

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people do something in response to an external influence, such as payment, or when someone important to them wants them to complete the task.

Deci and Ryan (1985, 2000) maintained that the achievement of high performance levels relied on three factors – competence, autonomy and relatedness. It is anticipated that in terms of sensory panels, each of these three factors could be manipulated to improve motivation. Competence requires a level of self-confidence, which can be defined as "cognitions that one is up to the task and able to give one's best possible performance" (Stoeber, Otto, Pescheck, Becker, & Stoll, 2007). The panelist and the panel leader can each play a role in improving and promoting the panelist's self-confidence. A sense of autonomy can be created if a panelist feels they are performing a task because they want to, not because they are compelled by external factors. Finally, a person needs to feel connected to the group by developing a sense of value as a contributing member, thus satisfying the need for relatedness. In summary, a person will be motivated if they have the ability to perform the task, feel that they have some control in performing the task, and that they have some relationship to the group involved in performing the task.

An example can be shown in sports psychology. Psychologists believe that people are more likely to perform better if they are self-determined, rather than if they are extrinsically motivated or amotivated (LaVoi, 2007). Consider the child who enjoys competitive swimming and practices faithfully, versus the child who must be compelled to practice. The child who voluntarily spends more time at practice would more likely become the better swimmer (Deci & Ryan, 2000). If panelists are intrinsically motivated to be trained panelists, they may be more likely to improve their performance as panelists (LaVoi, 2007).

Sports research literature also emphasises the motivating role of a coach who displays confidence, uses positive and persuasive language, and verbal rewards (Weinburg & Jackson, 1990). When a coach uses these motivational tools, the athlete's performance improves (Hollembeak & Amorose, 2005; Kais & Raudsepp, 2004; Katz & Assor, 2007; Mamassis & Doganis, 2004; Vansteenkiste, Matos, Lens, & Soenens, 2007; Vierling, Standage, & Treasure, 2007; Weinberg, Grove, & Jackson, 1992). Similar to the demand put on athletes, panelists must also consistently perform on command and to the best of their abilities, regardless of circumstances. The success of a sensory panel is dependent on the role of the panel leader in maintaining panelists' motivation (Moskowitz et al., 2005). The goal of a sports coach or panel leader is to create an environment that increases confidence and performance while preventing stress, anxiety, tension and burn out (Amorose & Anderson-Butcher, 2007).

Education research literature also discusses the balanced relationship between motivation and challenge. Without an appropriate amount of challenge, there is an increased risk that the performer could be discouraged rather than motivated by the challenge (Stoeber & Rambow, 2007). By analogy, we might expect that if a panelist is unable to recognize a specific sensory attribute they may become less motivated to continue the task, perceiving the challenge as too great. Equally, if the challenge is too low, the panelist may become bored. This circumstance might occur with panelists that have been on a panel for a long time – they may gradually lose motivation and interest as familiar panel work becomes routine, and thus perhaps less challenging.

The current research continues to investigate the relationship of motivation to trained panelist performance. This research examined what drivers inspired people to become trained panelists, measured the intensity of intrinsic motivation among trained panelists.

This research used two surveys to address the following questions:

1. What were the initial and subsequent drivers that motivated trained panelists?
2. Were trained panelists intrinsically motivated?
3. What differences in motivation were found between external panels and internal panels?
4. What differences in motivation were found between new panelists and experienced panelists?

2. Materials and methodology

2.1. Survey 1 – factors that inspire people to become and remain panelists

The aim of Survey 1 was to determine what factors inspired people to become panelists and what factors motivated them to remain panelists. Seven trained panels were surveyed ($n = 74$). Panelist age ranged from 25 to 65 years, and trained panel experience ranged from 1 year to more than 10 years. Survey 1 was administered to all panelists prior to their training session in December 2006. Descriptive analysis of specific products listed in Table 1 was the primary duty of Survey 1 panelists. These panelists were also involved in some difference testing. All panel leaders reported incorporating some form of panelist's performance feedback during panel work.

The panelists were asked to rank 10 motivational factors (Table 2), both intrinsic and extrinsic, that could have influenced their decision to become a panelist. Panelists were asked to rank all factors, giving a ranking of "1" to the most important factor through "10" as the least important factor. The questionnaires were filled out in individual booths prior to a standard training session. The panelists were instructed that the main goal of the research was to elicit their honest opinions and that there were no right or wrong answers. To ensure panelist anonymity, the use of identifying names or codes was omitted. The panelists were informed that this survey was part of study being done on many trained panels. Panelists were given the option of electing not to participate in the survey. The response rate was 100%. Survey 1 was analysed for significant differences at $P \leqslant 0.05$ using the Basker Ranking Sum Table (Basker, 1988).

Experienced panelists were asked to remember back to what influenced them to become a panelist. Most of the experienced panelists did not express difficulty with remembering why they were inspired to become a panelist, but it is important to bear in mind that memories can be altered over time.

2.2. Survey 2 – intrinsic motivation survey

The aim of Survey 2 was to measure trained panelists' intrinsic motivation. Intrinsic motivation inventory (IMI) is a method of

Table 1
Details about each panel used in Survey 1 and 2. Details include country of origin, type of panel, and products the panel tested.

Panel #	Country of origin	Type of panel	Products tested by panel
Survey 1			
1–6	New Zealand	External	Dairy products
7	New Zealand	External	Fruit and fruit products (i.e. wine)
Survey 2			
1	New Zealand	External	Dairy products
2	New Zealand	External	Dairy products
3	New Zealand	Internal	Dairy products
4	New Zealand	External	Fruit and fruit products (i.e. wine)
5	Spain	Internal	Fruit
6	Australia	Internal	Beer
7	USA	External	Processed products

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Table 2
Factors that trained panelists ($n = 74$) were asked to rate in order of importance as to what inspired them to become a panelist and what inspires them to remain a panelist.

Factor	Type of factor*
Extra income	Extrinsic
General interest in food	Intrinsic
Interest in new foods	Intrinsic
Social interaction	Intrinsic
Intellectual stimulation	Intrinsic
Friend/family was a panelist	Extrinsic
Recommended by a friend (become a panelist only)	Extrinsic
Something I do well	Intrinsic
I enjoy it (remain a panelist only)	Intrinsic
Promote research	Extrinsic
Prestige	Extrinsic

* Based on definitions in Deci and Ryan (2000).

gauging a participant's subjective experience of an activity such as trained panel work. The original IMI was developed by Ryan, Mims, and Koestner (1983) with 27 questions. McAuley, Duncan, and Tammen (1989) shortened the original IMI version by omitting redundant questions. Other researchers have used this short version IMI in measuring athletes' intrinsic motivation (Vierling et al., 2007).

Survey 2 was adapted from the modified IMI, developed by McAuley et al. (1989) for athletes, so as to be applicable to the motivation of trained panels (Table 3). Survey 2 measured factors which intrinsically motivate people to serve as a panelist (e.g. enjoyment or importance to self), as opposed to extrinsically motivating them, (e.g. income or praise). Survey 2 assessed five parameters of intrinsic motivation: interest/enjoyment, competence, value/usefulness, pressure/tension, and choice. The Survey 2 statements rated by the panelists are listed in Table 3. Seven trained panels ($n = 108$) from five companies/universities in four countries were surveyed (Table 1). All the panels from New Zealand who participated in Survey 2 also participated in Survey 1 as show in Table 1. The primary duty of Survey 2 was descriptive analysis of specific products listed in Table 1. Survey 2 was administered to the seven panels between February and May 2007, before their training sessions. Panel leaders in Survey 2 reported incorporating some form of panelist's performance feedback during panel work.

Table 3
Survey 2 modified intrinsic motivation inventory survey (McAuley et al., 1989) completed by trained panelists ($n = 108$). Panelists scored on a 7-point category scale [not at all true (0) to very true (6)].

IMI statement	Category
While I'm on the panel, I think about how much I enjoy it	Interest
I do not feel at all nervous about doing panel work	Pressure
I believe this panel work is of some value to me	Value/ usefulness
I think I am pretty good at my job on the panel	Competence
I find my panel work very interesting	Interest
I feel tense while doing panel work	Pressure
I think I do my job pretty well, compared to other panelists	Competence
Doing panel work is fun	Interest
I am willing to do this panel work because it has some value to me	Value/ usefulness
I feel relaxed with doing panel work	Pressure
I enjoy doing panel work very much	Interest
I don't really have a choice about doing panel work	Choice
I am satisfied with my performance on the panel	Competence
I am anxious while doing panel work	Pressure
I believe doing panel work is beneficial to me	Value/ usefulness
I think panel work is very boring	Interest
I feel like I am doing what I want to do while I do panel work	Choice
I feel pretty skilled at panel work	Competence
I think this is an important job	Value/ usefulness
I feel pressured while doing panel work	Pressure
I think panel work is very interesting	Interest
I feel like I have to do panel work	Choice
I would describe panel work as very enjoyable	Interest
I do panel work because I have no choice	Choice
After working on the panel for a while, I feel pretty competent	Competence

Panels were comprised of either internal or external panelists. Internal panelists were company employees who considered their participation in panel sessions to be a compulsory requirement of their job. In contrast, external panelists were volunteers who were primarily recruited from outside the company, and they were financially compensated for their service as panelists. As in Survey 1 the descriptive analysis of specific products listed in Table 1 was the primary duty of Survey 2 panelists.

The panelists were asked to rate the statements on a 7-point category scale with the end points anchored at "not at all true" (0) and "very true" (6). A one-way analysis of variance (ANOVA) was measured using the Generalised Linear Model (GLM) procedure in Minitab 15 (Minitab Inc., State College, PA. Release 15, 2006) to analyse Survey 2.

3. Results

3.1. Survey 1 – factors that inspire people to become and remain panelists

Based on the panelists' rankings from Survey 1, the most important factor in inspiring people to become a panelist was *income* (Fig. 1). However, this ranking was not statistically significantly higher ($P \leqslant 0.05$) than the ranking for *general interest in food* and *social interaction*, in inspiring people to become panelists. This result shows that intrinsic factors such as social interaction and interest in food were just as important as income, an extrinsic factor, in motivating people to become panelists.

The most important factors found for inspiring people to remain panelists were *enjoyment* and *income*, with no statistically significant difference between these two factors ($P \leqslant 0.05$), indicating that the intrinsic factor of enjoyment was just as important as payment in retaining panelists. Two other intrinsic factors, a *general interest in foods* and *social interaction* were also important influences that inspired people to sustain their commitment to continue working as panelists.

3.2. Survey 2 – measurement of panelists' intrinsic motivation in relationship to panel type and panelist's experience

Survey 2 was divided into five different parameters – *interest*, *competence*, *pressure*, *value/usefulness* and *choice*. Factor analyses showed that there were four main factors (Table 4). Factor 1 accounted for the largest variance in the data (29.2%), and was found to consist of both the *interest* and *value/usefulness* parameters, indicating a correlation between these two parameters. In the literature, *interest* and *value* are cited as being among the most important parameters in sustaining intrinsic motivation (McAuley et al., 1989). *Choice* was the primary component of Factor 2 (17.4%). *Competence* was the primary component of Factor 3 (14.2%), and *pressure* was the primary component of Factor 4 (8.4%) (Table 4).

Each statement of Survey 2 was analysed by the panel type (internal or external) and the respondent's length of time serving as a panelist. Means and P values of panelists' responses to Survey 2 are listed in Tables 5 and 6.

3.2.1. Effect of panel type – Internal versus external panels

The panel type had a significant effect on the factors related to *interest* (Table 5). External panelists found panel work *more*

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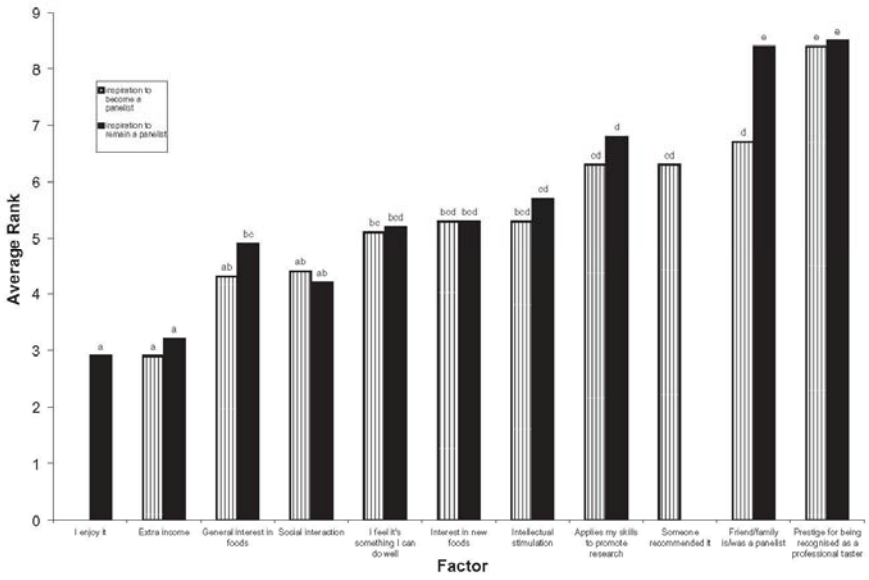

Fig. 1. Factors that inspire people to become and remain panelists ($n = 74$). Significant comparisons were made within each question ($P \leqslant 0.05$). The lowest the rank was the most important factor.

interesting ($P \leqslant 0.001$), *more fun* ($P \leqslant 0.01$) and *more enjoyable* ($P \leqslant 0.001$) than internal panelists. *Interest* is a key factor in fostering intrinsic motivation (McAuley et al., 1989).

The response from internal panelists indicated they had less *choice* about doing their job (panel work) than external panelists did ($P \leqslant 0.001$). While the internal panelists perceived they had some *choice* in performing the task, their mean scores were significantly higher than those of the external panelists for all the statements related to *not having a choice to do panel work* ($P \leqslant 0.001$) (Table 5). This result might be a consequence of their perception that panel service is a mandatory condition of their employment. The perceived lack of choice reduces their sense of autonomy and consequently may decrease their intrinsic motivation.

Compared with internal panelists, external panelists felt that panel work had more *value* ($P \leqslant 0.05$) and was more beneficial to them ($P \leqslant 0.01$). They also thought they were *better at their work* ($P \leqslant 0.01$) and more *skilled* ($P \leqslant 0.001$) (Table 5). These factors have been shown in the literature to contribute to higher quality of data through pride in their work (Ryan et al., 1983).

The type of panel had no effect on the *tension* or *pressure* that the panelists felt while performing panel work. The data indicated that they were generally relaxed and not anxious or tense while doing panel work.

3.2.2. Effect of years working as a panelist

The number of years that people worked as panelists had an effect on their perceived competence. Please note that the sample sizes are too small to show significant results and therefore must be regarded as trends. Panelists who had been working for 1 year or less had a lower opinion of their personal competence than the panelists who had worked 10 years or more ($P \leqslant 0.048$), and less experienced panelists did not think their competence had increased with time compared with more experienced panelists ($P \leqslant 0.01$) (Table 6). The new panelists (<1 year) and those with 5–7 years of panel experience were less satisfied with their performance and felt less competent than panelists with 8–10 years of experience ($P \leqslant 0.026$ and $P \leqslant 0.001$, respectively). These results show that panel leaders may need to focus on giving new panelists the skills they require to begin building their perceived competence.

Panelists with 8 or more years of experience felt they were the most skilled at panel work ($P \leqslant 0.001$) compared with all other experience levels. This may indicate that panelists who make it through 7 years of panel work may reach a high level of confidence in their panel skills. On the other hand, those panelists who were not confident at 5–7 years may have already quit the panel, thus increasing the percentage of confident panelists within the group of panelists that have attained 8 or more years of experience.

When looking at the *Interest* category, panelists with 5–7 years of experience enjoyed their jobs the least compared with other panelists ($P \leqslant 0.015$). For *Value/Usefulness*, panelists with 8–10 years of experience were less likely to agree that panel work was of some value to them ($P \leqslant 0.009$) or that it was beneficial to them ($P \leqslant 0.023$). Panel leaders may need to focus on helping more experienced panelists understand the ongoing value of their work. A longitudinal study of panelists over several years would yield a better understanding of how experience affects their confidence in their performance. There could have been confounding effects with the type of panel and experience level, but the experience range of the external panel was similar to the experience range of the internal panel. It would be expected this would limit the confounding effect.

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Table 4
Factor analysis (using varimax rotation) of modified Intrinsic Motivation Inventory survey from seven different trained sensory panels (n = 108).

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Interest/enjoyment				
While I'm doing panel work, I think about how much I enjoy	1.258	-0.142	-0.242	-0.042
I find panel work very interesting	1.177	-0.297	-0.190	0.094
Doing panel work is fun	1.207	-0.191	-0.287	0.273
I enjoy doing my job very much	0.998	-0.070	-0.400	0.099
I think panel work is very boring	-0.374	0.842	-0.095	-0.170
I think panel work is very interesting	1.215	-0.364	-0.267	0.021
I would describe panel work as very enjoyable	1.065	-0.547	-0.329	-0.045
Pressure/tension				
I do not feel at all nervous about doing panel work	0.532	0.343	-0.372	1.225
I feel tense while doing panel work	0.212	0.357	-0.024	-0.940
I feel relaxed with doing panel work	0.476	0.060	-0.458	0.776
I am anxious while doing panel work	0.090	0.270	0.199	-0.728
I feel pressured while doing panel work	-0.213	0.695	-0.115	-0.806
Value/usefulness				
I believe this panel work is of some value to me	1.109	0.097	-0.093	0.122
I am willing to do this panel work because it has some value to me	1.202	0.012	-0.129	0.132
I believe doing panel work is beneficial to me	1.287	-0.010	-0.221	0.069
I think this is an important job	0.677	0.038	-0.363	0.029
Competence				
I think I am pretty good at panel work	0.513	0.141	-0.950	0.239
I think I do my job pretty well, compared to other panelists	0.293	0.540	-1.616	0.042
I am satisfied with my performance at panel work	0.258	0.151	-0.891	0.287
I feel pretty skilled at panel work	0.493	0.102	-1.147	0.154
After doing panel work for a while, I feel pretty competent	0.183	-0.202	-0.930	0.028
Choice				
I don't really have a choice about doing panel work	0.021	1.638	-0.093	-0.042
I feel like I am doing what I want to do while I do panel work	1.261	-0.195	-0.299	0.015
I feel like I have to do panel work	-0.210	1.591	-0.149	-0.137
I do panel work because I have no choice	-0.191	1.325	-0.122	-0.265
Variance	15.936	9.499	7.754	4.585
% Variance	0.292	0.174	0.142	0.084

4. Discussion

4.1. Factors that motivate panelists

Sensory scientists know that financial compensation motivates panelists (Word & Gress, 1980); this was shown in Survey 1. However, in this survey, compensation was not found to be statistically significantly more important than a panelist's interest in food, which is an intrinsic motivating factor. As an external motivation factor, compensation does not engender self-regulating behaviour and therefore may not sustain consistent levels of performance.

When a task engages a person's intrinsic motivation, that person is more likely perform the task. Deci and Ryan (2000) provide the example of a person who enjoys playing the piano and is motivated by the sheer pleasure of the task. However, if that person is forced to play or overwhelmed by technical difficulties within the piece, they might begin to perceive playing the piano as a chore and not persist with the task. Intrinsic motivation requires autonomy (not feeling forced) and competence (being able to complete the task), and an appropriate level of challenge. Panelists who rated *I remain a panelist because I enjoy it* did so because they were intrinsically motivated. They felt their decision to be a panelist was an autonomous choice, and that they were able to complete the task and do it well. If a person participates in a panel because they are motivated by an extrinsic factor (money), then they may be less likely to perform consistently well (Deci & Ryan, 2000). Future research should include evaluating the intrinsic motivation of top-performing panelists compared with low-performing panelists.

4.2. Autonomy

When deciding what type of trained panel to establish, companies must often consider which panel type is the most cost effective yet enables them to make appropriate business decisions.

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Table 5
Sensory panels' mean scores and *P* values from responses to Survey 2 – external versus internal panel ($n = 108$). Panelists scored on a 7-point category scale [not at all true (0) to very true (6)].

Factor	*P* values	Mean scores*	
		External panel ($n = 76$)	Internal panel ($n = 32$)
Interest/enjoyment			
While I'm doing panel work, I think about how much I enjoy it	0.002	4.46a	3.38b
I find panel work very interesting	<0.001	5.63a	4.56b
Doing panel work is fun	0.002	5.50a	4.44b
I enjoy doing panel very much	<0.001	5.68a	4.63b
I think panel work is very boring	0.009	1.51b	2.31a
I think panel work is very interesting	<0.001	5.57a	4.27b
I would describe panel work as very enjoyable	<0.001	5.42a	4.12b
Pressure/tension			
I do not feel at all nervous about doing panel work	0.690	4.96	5.22
I feel tense while doing panel work	0.365	2.05	1.88
I feel relaxed with doing panel work	0.279	5.42	5.28
I am anxious while doing panel work	0.680	1.93	1.94
I feel pressured while doing panel work	0.271	2.07	2.45
Value/usefulness			
I believe this panel work is of some value to me	0.219	5.24	4.84
I am willing to do this panel work because it has some value to me	0.020	5.11a	4.31b
I believe doing panel work is beneficial to me	0.006	5.16a	4.25b
I think this is an important job	0.284	5.67	5.50
Competence			
I think I am pretty good at panel work	0.025	5.08a	4.56b
I think I do my job pretty well, compared to other panelists	0.690	3.99	3.84
I am satisfied with my performance at panel work	0.424	5.07	4.78
I feel pretty skilled at panel work	<0.001	5.11a	4.08b
After doing panel work for a while, I feel pretty competent	0.067	5.21	4.67
Choice			
I don't really have a choice about doing my panel work	<0.001	1.54b	3.63a
I feel like I am doing what I want to do while I do panel work	0.002	4.81a	3.78b
I feel like I have to do panel work	<0.001	1.42ba	3.55a
I do panel work because I have no choice	0.001	1.36b	2.60a

* Letters that are different within a row are significantly different at *P*-value stated.

Companies may not want, or cannot afford, the extra salary costs associated with external panelists. Although some companies might have a large pool of employees from which to gather sufficient numbers of volunteers, this convenience may not be possible for small or medium sized companies, and it may be necessary to assign employees to internal sensory panels. However, internal panels are not necessarily the optimum alternative solution.

Comparisons of the IMI surveys comparing data from external and internal panels showed that external panelists had higher scores for intrinsic motivation compared to internal panelists. The external panelists had experienced autonomous choice in their decision to apply and serve on panels. In contrast, internal panelists might not have anticipated any requirements to serve on panels as a condition of their employment. Consequently, they might consider any time spent as a panelist as an additional, non-negotiated requirement to the job they agreed to do. Our measurement of lower intrinsic motivational scores for this group of internal panelists reflects their attitude that participation in panels is an externally imposed demand on their time, reducing their perceptions of autonomy and their motivation to perform. Less reliable data could result in poor business decisions and higher costs. To mitigate these de-motivational influences, internal panelists could be allowed some specific compensation (in lieu time, or some pay differential) for their participation in panel work. Internal panelists should also be given sufficient time to perform normal duties so as not to add stress from too little time to complete their current work load.

In situations where the use of internal panels is unavoidable, it is crucial for panel leaders to cultivate as much panelist autonomy as possible. Panel leaders can allow panelists to choose their preference of meeting times, or allow them flexibility in their session attendance. It should be noted that these allowances for panelist autonomy will introduce some complications to the statistical analysis of the data and may have an adverse impact on the operation of the panel. External panels might cost more but offer the advantages of intrinsically motivated panels (higher scores in interest, choice, competency and value), which should lead to reduced panelist turnover. External panels should provide improved levels of performance and more reliable data, so these advantages may ultimately be the lower cost option for improved data quality and increased panelist retention.

4.3. Competency

Perceived competence was evident in highly experienced panelists, compared with panelists having little or no experience. The experienced panelist (>8 year) felt very competent. Stoeber et al. (2007) stated that self-confidence in a task can be highly associated to high levels of performance. Mastery of a task acquired through years of experience will build self-confidence.

Among panelists who have been working for 5–7 years, the moderate scores in perceived competence possibly relate to the repetition and familiarity of panel related tasks, with a concomitant perception that these tasks offer reduced challenge. Panelists' boredom could lead to a reduced focus on the task with a resultant decrease in performance, and consequently negative effects on the panelists' self-perception of task competency. Future work could correlate panelist age with years of experience, to determine if age has a relationship with perceived competency.

As could be expected, panelists with less than one year of experience felt they lacked competency compared with the more experienced panelists. The data suggest that after a year of experience,

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Table 6
Sensory panels' mean scores and *P* values from responses to Survey 2 – length of time serving as panelists (years) (n = 108). Panelists scored on a 7-point category scale [not at all true (0) to very true (6)].

Factor	*P* values	Length of time working as panelists Mean scores*				
		< 1 year (n = 13)	2–4 years (n = 28)	5–7 years (n = 25)	8–10 years (n = 17)	>10 years (n = 25)
Interest/enjoyment						
While I'm doing panel work, I think about how much I enjoy it	0.795	4.23	3.96	4.28	4.12	4.08
I find panel work very interesting	0.823	5.62	5.32	5.12	5.24	5.42
Doing panel work is fun	0.554	5.38	5.32	4.84	5.18	5.29
I enjoy doing my job very much	0.081	5.77	5.11	4.96	5.59	5.71
I think panel work is very boring	0.234	1.46	1.64	1.76	1.41	2.25
I think panel work is very interesting	0.161	5.77	5.29	4.72	5.24	5.19
I would describe panel work as very enjoyable	0.465	5.73	5.15	4.72	4.88	5.15
Pressure/tension						
I do not feel at all nervous about doing panel work	0.884	5.69	5.04	4.76	5.00	4.96
I feel tense while doing panel work	0.233	2.00	2.04	2.40	1.47	1.92
I feel relaxed with doing panel work	0.654	5.54	5.25	5.12	5.41	5.67
I am anxious while doing panel work	0.081	2.38	1.75	2.24	1.53	1.88
I feel pressured while doing panel work	0.399	2.45	2.22	1.92	1.82	2.54
Value/usefulness						
I believe this panel work is of some value to me	0.014	5.00ab	5.29ab	4.96ab	4.29b	5.79a
I am willing to do this panel work because it has some value to me	0.410	4.92	4.93	4.76	4.41	5.25
I believe doing panel work is beneficial to me	0.076	5.08ab	5.07ab	4.80ab	4.06b	5.21a
I think this is an important job	0.179	5.92	5.54	5.28	5.47	6.04
Competence						
I think I am pretty good at panel work	0.002	4.15b	4.86b	4.64b	4.82b	5.75a
I think I do my job pretty well, compared to other panelists	0.049	3.00b	3.79ab	3.76ab	3.94ab	4.75a
I am satisfied with my performance at panel work	0.021	4.54b	4.79ab	4.72ab	5.65a	5.21ab
I feel pretty skilled at panel work	<0.001	3.77b	4.54b	4.24b	5.59a	5.65a
After doing panel work for a while, I feel pretty competent	0.008	4.00b	5.04ab	4.80ab	5.35ab	5.56a
Choice						
I don't really have a choice about doing panel work	0.032	1.77	1.64	2.28	1.82	3.13
I feel like I am doing what I want to do while I do panel work	0.340	4.77	3.96	4.48	4.65	4.88
I feel like I have to do panel work	0.505	2.00	1.67	2.16	1.59	2.46
I do panel work because I have no choice	0.784	1.55	1.59	1.60	1.59	2.10

* Letters that are different within a row are significantly different at *P*-value stated.

panelists gain confidence in their competency. It will be important in future research to verify if panelists' perception of competency positively correlates with their performance.

Positive and negative cues from the panel leader can affect certain panelists but will probably have a stronger influence on panelists with lower levels of intrinsic motivation. Previous research showed that when experienced panelists were given negative verbal cues, they responded positively, perceiving the negative feedback as a challenge, which in turn improved their competency and their performance levels (Lund, 2005). If a panelist lacks competency negative cues from the panel leader are more likely to have a negative impact and lead to poor performance.

The panel leader needs to be aware of appropriate levels of challenge. Reinboth, Duda, and Ntoumanis (2004) confirmed that when a coach provided a training environment of autonomy and relatedness, and introduced challenge, this combination improved both the athlete's performance as well as the athlete's perceptions of their own competence. Panelist experience is also important to consider in examining motivation because motivation may decrease with continuing panelist experience as the panel work becomes less challenging, or less intrinsically motivating. Panel leaders need to be able to provide enough challenge such that the intrinsic motivation of 5- to 7-year experienced panelists is fostered, but not so much challenge that the newer panelists lose interest.

Understanding motivation is critical, not only in trained panel but with consumer panels as well. Frandsen, Dijksterhuis, Martens, and Martens (2007) were able to motivate their consumer panelists by creating a psychological challenge. Their Danish consumer panelists were initially unable to perceive a difference between two milk products via a difference test. In a subsequent session, researchers informed the consumer panelists that one product was a Danish milk and the other was a foreign milk, and asked the panelists to see if they could discern a difference. The difference test from this second session yielded a significant perceived distinction between the products. Apparently providing additional information to the panelists increased their ability to discern a difference between the two products. This improved discerning ability could imply the consumers were more motivated to perceive a difference between the products.

4.4. Relatedness

The panel leader can greatly influence the panelists' feelings of relatedness as important and valuable members of the panel. Providing performance feedback, using positive verbal cues, and discussing the importance of accomplished panel goals are some of the tools a panel leader can use to foster panelists' experience of relatedness. Amorose and Anderson-Butcher (2007) found that those coaches who were supportive of an athlete facilitated that athlete's abilities to build and sustain intrinsic motivation. Further research should investigate the effects of a panel leader's positive influence in developing panelists that who feel supported and valued.

Feedback is an important tool that the panel leader can utilise in motivating panelists to increase their feeling of group relatedness.

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A study that evaluated the effects of coaches providing feedback to teachers showed that this feedback played a role in engaging the teachers in their student assessment task. Teachers were motivated to become involved with their student assessment duties through this coach involvement (Denton, Swanson, & Mathes, 2007). With respect to panelists, this research would suggest that giving an individual feedback on their performance would be intrinsically motivating. If a panelist is genuinely interested in panel work, they will want to improve their performance just as a pianist who is passionate about playing will enjoy practicing, because it is improving their skill. Panel leader's feedback is a way to engage panelists and make them feel connected to the group. Feedback could come from summary reports, panel leaders and other panelists.

4.5. Panelist recruitment

Currently many sensory scientists screen new panelists for physiological acuity. Sensory scientists test for taste and odour acuity, but it may be beneficial to seek a motivation profile test that could be used when screening new panelists. Literature suggests that sensory scientists should advertise for panelists in food sections of newspaper and that good panelists should show a passion or interest in food (Stoer & Rodriguez, 2002), which our results show was an important intrinsic motivation factor for panelists. Through a screening questionnaire a panel leader could determine whether working with food is an interest of the panelist. This would give information on whether there is the potential for intrinsic motivation to occur.

4.6. Future Research

More research is needed for a better understanding of the relationship between panelist performance and their level of intrinsic motivation. Future research should focus on comparisons of levels of intrinsic motivation, to determine this factor's effectiveness in panel performance directly. Longitudinal studies would aid in the understanding of the effects of panelists' experience. Collaborations, as conducted in data collection of Survey 1 and 2, might help in acquiring a larger sample size, removing the limitations of the usual 8–10 person panel.

With a comprehensive understanding of motivational factors the panel leader could tailor their approach for each panelist. Good panel leaders probably adapt their responses intuitively, but improving and defining this process could assist all panel leaders.

5. Conclusion

It is the goal of the panel leader to get the most from their panel in terms of performance and results. Understanding what motivates them is an important tool to have in their toolbox, as this will lead to better performance and less boredom. Better understanding of human behaviour will aid in modification panel training, panel interactions, and the social climate that can help in fostering intrinsic motivation. When panelists are intrinsically motivated in their work they will experience increased enjoyment, well being, and satisfaction, which in turn will lead to sustained participation and improved performance.

This research showed that panelist experience as well as panel type (internal and external) plays a role in motivation. Using panels that are highly intrinsically motivated is vital to maintaining the value of trained panels. Panel leaders can foster intrinsic motivation by acquiring panelists that are competent, by creating an environment in which panelists feel relatedness and experience autonomy in their task, and by using positive verbal cues. Different individual panelist might be motivated by different influences, and it is the understanding of these factors that will lead to intrinsically motivated, well-performing panels and ultimately, less training time, reduction in panelist turnover, lower costs and higher quality data.

6. Uncited reference

Hanton et al. (2004). Q1

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Appendix K: PUBLICATION OF CHAPTER 3

New Zealand Sauvignon blanc Distinct Flavor Characteristics: Sensory, Chemical, and Consumer Aspects

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Abstract: A trained sensory panel (n = 14) identified key flavors in Sauvignon blanc wines from Australia, France, New Zealand, Spain, South Africa, and the United States. Sixteen characteristics were identified and measured: sweet sweaty passion fruit, capsicum, passion fruit skin/stalk, boxwood/cat urine, grassy, mineral/flinty, citrus, bourbon, apple lolly/candy, tropical, mint, fresh asparagus, canned asparagus, stone fruit, apple and snow pea. Principal component analysis was used to describe differences among regions and countries. Sauvignon blanc wines from Marlborough, New Zealand, were described by tropical and sweet sweaty passion fruit characteristics, while French and South African Sauvignon blanc wines were described as having flinty/mineral and bourbon-like flavors. Chemical analyses of these wines also showed that wines from Marlborough had more methoxypyrazine and thiol compounds. A consumer study (n = 105) showed that New Zealanders significantly prefer New Zealand-style Sauvignon blanc.

Key words: Sauvignon blanc wine, region, trained panel, sensory analysis, consumer

The "typicity" for products has been the focus of recent research in Europe (Iaccarino et al. 2006, Martinez Carrasco et al. 2005). The term is used to convey those wine qualities and flavor characteristics that can be expected from a region, which is defined as a broad geographic area distinguished by similar features. In this research, a region is a named area of land. In France, the Appellation d'Origin Controlee (AOC) was established to regulate quality from designated wine-producing regions. Geographic influences on wine sensory profiles have been investigated extensively, including studies on wines made from grape varietals such as Albarino (Vilanova and Vilarino 2006), Touriga Nacional (Falque et al. 2004), Riesling (Douglas et al. 2001), Chardonnay (Schlosser et al. 2005), and Pinot noir (Cliff and Dever 1996). Through the evaluation of sensory characteristics and/or chemical composition, these studies have found regional or subregional differences among the wines. We were interested in determining differences among Sauvignon blanc from different geographical sources in terms of chemical composition and sensory profiles, in combination with consumer preferences. The current study also focused on wines from three regions within New Zealand and compared them with wines produced in five other countries.

Sauvignon blanc wine has distinctive sensory characteristics, both fruity (passion fruit, gooseberry, citrus, tropical) and green (capsicum, asparagus, grassy, leafy) (Cooper 2002). These descriptors have been attributed to key chemical aroma and flavor compounds occurring in the wine. These characteristics have been ascribed to the thiol by-products of yeast fermentation (Tominaga et al. 2000, 1998). The yeast acts upon the odorless thiol precursors in the grapes to produce aromatic thiol compounds in the wine, which have been described as having notes of passion fruit, sweaty, tropical, boxwood, cat's urine, broom, and grapefruit (Charters 2004, Dubourdieu et al. 2006). It has been postulated that these thiols attribute to the varietal style of Sauvignon blanc wine because they are present in levels much higher than their established perception thresholds (Tominaga et al. 1998). Some yeast produce greater concentration of thiols, making these attributes even more intense (**Sweiger** et al. 2007). Earlier research has accredited the characteristic capsicum, herbaceous, and green notes in Sauvignon blanc to the methoxypyrazines (Allen and Lacey 1999, Lacey et al. 1991). Unlike the thiols, which only occur after fermentation has begun, the methoxypyrazines are

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present in the grapes, and their concentrations remain relatively constant during the fermentation process. Methoxypyrazine levels measured in grapes appear to be higher in those cultivated in cooler climates such as New Zealand (Lacey et al. 1991).

One study on closure types and their subsequent effect on the chemical concentrations and flavors of Sauvignon blanc wines demonstrated that, after a year of storage, wines bottled under screwcap underwent very little change in flavor when compared with wines bottled under cork (Brajkovich et al. 2005). The wines with different closures were chemically analyzed for thiols, oxygen, and sulfur dioxide, and then sensorially assessed for six descriptive attributes (capsicum, sweet sweaty passion fruit, passion fruit skin/stalk, cat urine, grassy, flinty/mineral). Another study compared Sauvignon blanc, Chardonnay, and Semillon juice through descriptive analysis (Francis et al. 1994), although the sensory attributes of thiols could not be examined as researchers were evaluating unfermented grape juice and thiols are only present in finished wine. The Sauvignon blanc juice expressed a strong capsicum characteristic in comparison to the other varietal juices.

Winemaker opinions of the Marlborough-style wine were recently evaluated (Parr and et al. 2007). To strengthen the understanding of geographical influences on the flavor characteristics of N.Z. Sauvignon blanc, the current study attempted to provide an objective, scientific correlation of sensorial evaluations with chemical results.

This research of N.Z. Sauvignon blanc began with a narrow assessment of the sensory differences among 28 N.Z. Sauvignon blanc wines selected from the 2003 vintage and found significant differences among the six regions examined (Lund et al. 2005). The study did not include any comparative international samples. Using six sensory attributes to evaluate each wine, the researchers found that Hawke's Bay Sauvignon blanc wines were high intensity in mineral flinty characteristics, whereas Marlborough wines were high intensity in sweet sweaty passion fruit and capsicum characteristics. Wairarapa wines had higher intensity in cat urine/boxwood characteristics. Some of the wines from specific regions showed measurable differences in their flavor profiles. Based on the results from the N.Z. 2003 vintage, another 35 Sauvignon blanc wines from the N.Z. 2004 vintage were selected from these three regions. Sauvignon blanc wines used in the current study of the 2004 vintage were selected from regions that had shown flavor differences in the 2003 vintage wines (Lund et al. 2005).

Wine marketers and writers claim that Marlborough Sauvignon blanc has distinctive flavors compared with Sauvignon blanc wines produced from other regions (Cooper 2002). In the research presented here, commercially available wines were evaluated to investigate whether Marlborough Sauvignon blanc wine exhibits regionally distinctive flavors as compared with wines from France, Australia, South Africa, Spain, and the United States. Defining the sensory profiles of Sauvignon blanc will aid in understanding the flavors and the chemicals associated with these flavors. Ultimately this research may facilitate the use of chemical measurements to predict descriptive attributes of wine.

Marlborough Sauvignon blanc contributes significant revenue to the N.Z. economy, and the ability to maintain a global position as a market leader for this varietal is critical to the success of the New Zealand wine industry. Scientific exposition of the distinctive flavors of Marlborough Sauvignon blanc may give wine producers the validity to substantiate their marketing claims, and thus benefit the N.Z. economy with increased export sales.

Materials and Methods

Wine. In order to provide a comprehensive sensory evaluation of Sauvignon blanc and to promote a diverse elucidation of definitive flavor profiles, the sensory panel used descriptive analysis to define the sensory characteristics of 52 Sauvignon blanc wines from six countries. Of the 52 wines, 49 were analyzed chemically and eight were selected for further assessment by a consumer panel. The wines were from New Zealand (Hawke's Bay and Wairarapa in the North Island, and Marlborough in the South Island), France (Sancerre, Loire Valley, Bordeaux), Spain (Rueda), South Africa (Stellenbosch), Australia (South Australia, Western Australia, Victoria), and the United States (Napa Valley, Russian River, and Sonoma in California and Columbia River in Washington). Four to five wines from each country were included in the study, but only two wines could be acquired from Spain (Table 1). Wines were selected on the basis of being predominantly from the Sauvignon blanc grape (>90%). Most of the 52 wines were tank-fermented wine, with little or no oak aging. However, one Hawke's Bay, one Australian, one American, and two French wines were aged in oak barrels. Oak aging is not a common practice in the production of New Zealand Sauvignon blanc wines, as it is with French Sauvignon blanc. Oak aging reportedly contributes smoky, spice, coconut, and vanilla flavors (Goode 2006). Although oak aging might introduce a confounding effect on the interpretation of the results of this study, several oak-aged samples were included in the descriptive analysis testing, as these wines represent a particular stylistic rendition of Sauvignon blanc available to consumers.

All southern hemisphere wines were selected from the 2004 vintage. The availability of wines from the northern hemisphere at the time of this study was limited to wines from the 2003 vintage, with the exception of one French and two Spanish wines, which were from the 2004 vintage. The retail price of the wines (sometimes used as a proxy for commercial assessment of quality) ranged from US$6.00 to $20.00 per bottle, with most wine prices falling between US$8.00 and $14.00.

Standard chemical wine analysis was performed on all of the wines to attain residual sugar, ethanol, pH, and titratable acidity. Upon completion of the flavor sensory testing, flavor chemical component analyses were con-

ducted on each wine. Wine samples were tested in triplicate for all analyses.

The eight wines chosen for the consumer study comprised a broad range of Sauvignon blanc wine styles, as delineated by the results of the descriptive analysis in the current study. Wines selections were sourced from France, Australia, South Africa, and New Zealand (Hawke's Bay, Wairarapa, and Marlborough) on the basis of their common commercial availability within the N.Z. market. Marlborough Sauvignon blanc dominates the N.Z. wine market, so three Marlborough wines were included for assessment by the consumer panel. All wines selected for the consumer study were chosen because they represented a distinctive regional flavor profile and not necessarily because they represented what might be regarded as a "typical" regional flavor profile.

Trained panelists. For descriptive analysis, 27 panelists experienced with descriptive analysis were screened for their ability to assess odor and taste, as well as for their cognitive (flavor memory) and descriptive language skills. Fourteen people were selected for the final panel based on their performance for providing correct answers in screening tests. None of the panelists had prior experience in wine assessment. The final panel was comprised of three males and 11 females, ranging in age from 27 to 55 years, and they were paid an hourly wage. Panelists developed the lexicon and reference standards, following normal descriptive analysis (Lawless and Heymann 1999). Panelists completed 70 hours of training in descriptive analysis and in the sensory evaluation of Sauvignon blanc wine.

Table 1 Number of wines analyzed by descriptive analysis in each region (n = 52).

Region	Quantity
New Zealand	
Marlborough	16
Wairarapa	7
Hawke's Bay	7[a]
South Africa, Stellenbosch	6
Australia	5
South Australia	
Western Australia	
Victoria	
United States	5
Napa Valley, CA	
Russian River, CA	
Sonoma, CA	
Columbia River, WA	
France	4[b]
Sancerre	
Loire Valley	
Bordeaux	
Spain, Rueda	2[c]

[a]One wine was not chemically analyzed.
[b]One additional wine was chemically analyzed.
[c]Neither wine was chemically analyzed.

Consumer panelists. Panelists were recruited on the basis that they were wine consumers. Panelist Sauvignon blanc consumption was evaluated but not used as a selective criteria for recruitment. The authors felt it was more important to understand the preferences and purchasing behaviors of a general wine consumer rather than limit the focus to only Sauvignon blanc wine consumers. Panelists were recruited from wine shops, from the HortResearch workplace, and by word of mouth. Remuneration for participating in the study consisted of a bottle of wine. The 109 consumers evaluated all eight wines chosen for the study.

Facility and evaluation. All sensory testing was performed in booths with green lighting at the HortResearch Sensory and Consumer Science Facility in Mt. Albert, Auckland. A positive airflow was maintained to reduce any odors not associated with the wine. Wine was served at 20°C in standard ISO wine glasses (Gilmours, NZ) with watchglass lids. Double-filtered (Lawless and Heymann 1999) water and plain water crackers were used as palate cleansers. Trained panelists received 20 mL of each wine for testing while consumer panelists received 15 mL of each wine. Both the trained and consumer panel were monadically served samples in a randomized presentation order. The wines were rated on a 150-mm unstructured linescale. The trained panelists rated the intensity of each attribute, from "absent" to "extreme," on an unstructured linescale. The consumer panel rated their overall liking of the each wine, from "dislike extremely" to "like extremely," on a 150-mm unstructured linescale. Panelists were permitted to retaste samples if necessary. Consumers were also asked demographic information and purchase behavior questions.

Descriptive analysis. Trained panelists evaluated the 52 wines in triplicate. Panelists evaluated 10 to 11 wines per session, with a 30-sec break after each wine and a 5-min break after every three wines to reduce sensory fatigue. Each panelist returned for 15 sessions so that each individual panelist tasted every wine. Variations were made to the presentation order of wine samples served concurrently to all panelists and to the presentation order of subsequent replicate samples provided to individual panelists.

Assessing 52 wines within a single session cannot be reliably accomplished without encountering the deleterious effects of panelist sensory fatigue. Likewise, when the assessment of a large number of wine samples is scheduled to extend over the course of several panel sessions, there will be the challenge of ensuring that every panelist attend every session. An incomplete randomized block design was applied to manage these challenges. The panelists were given the samples randomly and the randomized samples were blocked by replication (1, 2, 3).

The panelists rated intensities of 16 attributes on computers using Compusense software, version 5.0 (Guelph, Canada). The attributes and their reference standards evaluated are listed in Table 2.

Methoxypyrazine analysis. The quantification of 2-methoxy-3-isobutylpyrazine (MIBP) and 2-methoxy-3-isopropylpyrazine (MIPP) was performed according to a published method (Kotseridis et al. 1999). In brief, the organic phase of a triple extraction of 200 mL of wine (pH 8) with 1:1 diethyl ether:hexane is concentrated down to 100 µL and 2 µL are analyzed by gas chromatography (GC) coupled with mass spectrometry (MS) using a capillary column BP20 (50 m x 220 µm x 0.25 µm). Two modifications were made to this initial method: (1) the use of 2-methoxy-3-([$^2H_3$]isobutyl)pyrazine as an internal standard instead of 2-methoxy-3-([$^2H_2$]isobutyl)pyrazine and (2) the use of 2-methoxy-3-methylpyrazine as an internal standard for the quantification of MIPP.

The quantification **ions** of the 2-methoxy-3-([$^2H_3$]isobutyl)pyrazine **was** ion *m/z* = 127; ions *m/z* = 154 and 169 were used as qualifiers. For 2-methoxy-3-methylpyrazine, the ion *m/z* = 124 was used as the quantifier and ion *m/z* = 106 as the qualifier. The quantification ions of the MIBP and MIPP were **ions** m/z 124 and 137, respectively, and the ions *m/z* 151, 164 and 124, 152, respectively, were used as qualifiers.

The standard curve was prepared by adding increasing quantities (from 2 to 50 ng/L) of MIBP and MIPP to a Sauvignon blanc wine (Marlborough, 2004 vintage) to obtain eight different concentrations. The regression equation obtained was Y = 1077 X – 1.3699 with r^2 = 0.9957 for MIBP and Y = 1526.1X + 0.4395 with r^2 = 0.9991 for MIPP. Relative standard deviations of 4.8% and 6.2% were obtained for MIBP and MIPP, respectively, by assessing 10 samples of the same wine.

Volatile thiols. An established method (Tominaga et al. 1998, 2006) was used to determine the level of 3-mercaptohexyl acetate (3MHA) and 3-mercaptohexan-1-ol (3MH), using 4-methoxy-2-methyl-2-mercaptobutane as an internal standard. The thiols were extracted from 50 mL of wine using *p*-hydroxymercuribenzoic acid, which was then fixed onto an anion exchange column before the thiols were eluted with cysteine and extracted into dichloromethane prior to concentration and manual injection of 2 µL onto an Agilent 6890N GC with an 5973 MS detector (Agilent, Santa Clara, CA). The thiols were separated on a 50 m BP20 capillary column (220 x 0.25 µm) using He carrier gas at 28 cm/s and an oven temperature ramping from 40 to 220°C for a 71-min run.

Standard curves were obtained by adding increasing quantities of the two volatile thiols to a Sauvignon blanc wine (50 to 500 ng/L 3MHA; 500 to 5000 ng/L 3MH). The coefficient of determination (r^2) was 0.990 for 3MHA and 0.997 for 3MH. The reproducibility of the method was evaluated by repeating the analysis of the same Sauvignon blanc wine six times under constant operating conditions. Relative standard deviations of 6% and 5% were obtained for 3MHA and 3MH, respectively. Thiol extraction was according to a published method (Tominaga and Dubourdieu 2006).

Statistical analysis. Analysis of variance (ANOVA) was determined using residual maximum likelihood (REML), with region selected as the fixed effects and panelist/bottle + region/wine/bottle selected as random effects using GenStat, release 8.1 (Lawes Agricultural Trust, UK). Because of the unequal numbers of wines from each region, standard error of differences (SED) and least significant differences (LSD) vary for each pairwise comparison (Table 3). Principal component analysis (PCA) and canonical variate analysis (CVA) were em-

Table 2 Sauvignon blanc sensory reference standards used in trained panel evaluations.

Lexicon	Reference standard
Sweet sweaty passion fruit	2,000 ng/L 3-mercaptohexyl acetate (Oxford Chemicals)[a]
Capsicum	1,000 ng/L 2-methoxy-3-isobutylpyrazine (Acros Organics)[a]
Cat urine/boxwood	1,000 ng/L 4-mercaptomethyl pentane (Oxford Chemicals)[a]
Passion fruit skin/stalk	2,000 ng/L 3-mercaptohexan-1-ol (Interchim)[a]
Grassy	28,800 ng/L *cis*-hex-1-en-2-ol (Sigma)[a]
Flinty/mineral	4,000 ng/L benzyl methyl thiol (Oxford Chemicals)[a]
Citrus	30 g Yen Ben lemon plus 15 g Bear lime soaked in base diluted base wine 30 min[b]
Bourbon	2,400 µg/L hexanol (Sigma)[a]
Apple lolly/candy	2,50 mg hexyl acetate (Sigma)/L[a]
Tropical	40 mL Golden Circle Mango juice plus 40 mL Golden Circle Golden Pash drink plus 200 mL Just Juice Mandarin Passion Fruit juice[b]
Mint	25 mg/L cineole (Sigma)[a]
Fresh asparagus	50 mL steamed asparagus water[b]
Canned asparagus	10 mL Watties canned asparagus juice[a]
Stone fruit	Canned Watties apricot and peach juice soaked in diluted base wine 30 min (equal parts)[b]
Apple	70 g Sciros/Pacific Rose apple peeled, soaked in diluted base wine 30 min[b]
Snow pea	1,275 ng/L 2-methoxy-3-methylpyrazine (Acros Organics)[a]

[a]Added to diluted base wine (50% Corban Sauvignon blanc and 50% water).
[b]Added equal parts to base wine (Corban Sauvignon blanc).

Table 3 Sensory attribute means in Sauvignon blanc wines sampled from different regions.

Region	Sweet sweaty passion fruit	Capsicum	Cat urine	Passion fruit skin/stalk	Grassy	Flinty/mineral	Bourbon	Apple candy	Tropical	Citrus	Mint	Canned asparagus	Fresh asparagus	Stone fruit	Apple	Snow pea
Australia	47.7 ^{cf}	28.5	34.6 ^{d}	41.3 ^{b}	24.4	26.8 ^{a}	25.6 ^{abc}	28.0	20.2 ^{bc}	37.7	18.3	9.1	10.7 ^{bc}	26.4 ^{b}	27.3 ^{ab}	11.4 ^{ab}
France	46.5 ^{c}	30.0	39.6 ^{bcd}	42.7 ^{b}	24.2	30.9 ^{a}	26.3 ^{abc}	23.8	16.6 ^{c}	36.7	17.7	14.6	11.7 ^{bc}	28.9 ^{ab}	26.2 ^{ab}	10.2 ^{ab}
Hawke's Bay	51.9 ^{bc}	29.5	40.2 ^{bcd}	44.4 A^{b}	22.3	28.0 ^{a}	24.1 ^{bc}	27.4	21.6 ^{bc}	40.1	16.8	10.4	12.6 ^{bc}	29.4 ^{ab}	26.7 ^{ab}	11.7 ^{ab}
Marlborough	60.6 ^{a}	32.5	43.2 ^{ab}	48.1 ^{a}	22.7	20.3 ^{b}	18.4 ^{d}	25.8	32.3 ^{a}	39.8	17.2	8.6	16.9 ^{b}	32.8 ^{a}	29.4 ^{ab}	14.0 ^{a}
South Africa	51.5 ^{bc}	28.8	41.2 ^{abc}	40.8 ^{b}	21.1	29.3 ^{a}	27.1 ^{ab}	25.6	19.1 ^{bc}	38.2	15.3	12.5	11.2 ^{bc}	26.4 ^{b}	24.4 ^{b}	12.2 ^{ab}
Spain	60.2 ^{ab}	29.4	51.8 ^{a}	43.1 ^{ab}	19.6	28.7 ^{ab}	21.1 ^{bcd}	21.6	20.0 ^{bc}	36.1	14.9	5.2	13.4 ^{a}	24.9 ^{b}	23.9 ^{ab}	6.7 ^{b}
USA	47.9 ^{c}	28.7	36.9 ^{cd}	42.4 ^{b}	23.0	27.0 ^{a}	31.3 ^{a}	27.2	19.8 ^{bc}	34.6	16.1	11.4	8.8 ^{c}	28.5 ^{ab}	24.6 ^{ab}	10.0 ^{ab}
Wairarapa	57.5 ^{ab}	30.4	42.2 ^{abc}	45.3 ^{ab}	22.5	25.9 ^{ab}	21.0 ^{cd}	25.3	25.5 ^{b}	40.5	15.3	13.5	19.8 ^{a}	31.8 ^{ab}	29.5 ^{a}	13.2 ^{ab}
SED[a]	2.9	1.7	3.5	2	1.5	2.9	2.4	1.9	3.3	2.4	1.1	2.9	2.7	2.2	2.2	1.9
p value	<0.001	0.010	0.004	<0.001	0.16	<0.001	<0.001	0.15	<0.001	0.11	0.010	0.065	<0.001	<0.001	0.007	0.016
Std dev.	29.2	25.5	28.8	25.8	20.7	25.4	23.4	29.1	23.3	26.6	18.3	25.8	19.6	22.8	22.1	16.2

[a]SED comparing regions with the largest (Marlborough [n = 16]) and smallest (Spain [n = 2]) sample size. This is a conservative value taking into account different replications among regions.
[b]Different letters in the same columns indicate significant difference ($p < 0.05$)

ployed using the fitted wine means for each of the 16 attributes in the descriptive analysis data (SAS Institute, Cary, NC). A one-way ANOVA was used to determine differences between the regional chemical concentration analysis and other standard chemical analysis, such as sugar content and pH, using Fisher's LSD with 95% confidence level ($p < 0.05$).

Partial least squares regression (PLSR) was performed (Unscrambler, version 9.1, CAMO, Oslo, Norway) to determine the relationships among three chemicals and all sensory data. Three of the chemicals (3MHA, 3MH, MIBP) contributed to the prediction of the sensory characteristics, but MIPP did not contribute and was therefore omitted from the PLSR analysis.

The overall liking scores collected from the wine consumers were analyzed using a one-way ANOVA ($p < 0.05$) in GenStat. The preference map analysis was conducted in R (R Development Core Team, Vienna, Austria), which took the individual scores of the preference data and projected them into the two-dimensional space of the sensory attributes. A generalized Procrustes analysis (GPA) was performed in R to correlate sensory and consumer data and determine the different clusters of consumers for each flavor profile.

Results

Sensory analysis. Descriptive analysis revealed that the Marlborough wines had distinctive sensory characteristics with intensity levels that exceeded those of the international wines (Table 3). Several attributes (grassy, apple candy, citrus, and canned asparagus) did not show significant *p* values among different regions. The lack of significance among regions for those attributes was compounded by wide variation in the attribute measurements of wine samples from within a single wine region. Consequently, wines from a specific region may not necessarily display homogenous sensory intensities for those particular attributes.

Principal component analysis (PCA) gives a pictorial relationship of the wines based on their sensory attributes (Figure 1). The PCA simplifies the interpretation of multivariate analyses by extracting two or three dimensions that display the maximum amount of variability among the data. Wines that are very similar appear close to each other. In comparison, canonical variate analysis (CVA) extracts the dimensions that display the maximum amount of variation among the groups of wines from different regions (Heymann and Noble 1989). Results of both the PCA and the CVA were consistent in identifying relevant regional attributes within the data (Figure 2).

With the exception of the wines from Hawke's Bay, N.Z. regional wines were clearly distinguishable from international wines (Figure 1a). Marlborough and Wairarapa wines showed high attribute intensities for fresh asparagus, sweet sweaty passion fruit, capsicum, passion fruit skin/stalk, tropical, stone fruit, and apple, which comprised most of the variation of the data shown on

the x axis (principal component 1; PC1). In contrast, the wines from South Africa, France, Australia, United States, and Hawke's Bay were characterized by attributes of bourbon, flinty/mineral, and canned asparagus. The variation explained by PC1 was 47.4%. On PC2 (variation explained 14.1%), the wines on the bottom half of the graph displayed more strongly the boxwood/cat urine attribute, while those wines at the top were more intense in the apple lolly/candy characteristics (Figure 1a). To improve the clarity of the plotted data, attributes with joint correlation in PC1 and PC2 of less than 0.5 in absolute value were not labeled on the PCA graph. Although all attributes were included in the analyses, not all attributes were displayed in Figure 1.

Principal component 3 (PC3) (explaining an additional 9.7% variation) further clarified the data (Figure 1b; the attributes on PC1 are the same as in Figure 1a). Wines in the top half of the graph are separated by the presence of asparagus notes (both canned and fresh). Wairarapa wines appeared to have higher levels of both fresh and canned asparagus characteristics; Marlborough wines had more fresh asparagus notes; and international wines had more canned asparagus notes.

The ellipses represent statistical significance at the 95% confidence level around the means of each region (Figure 1a). Because there were only two Spanish wines, they are connected by a single line. The Marlborough mean and ellipse shows no overlap with the international wines, but does show some similarities with the Wairarapa wines.

In CVA, each wine region is represented by a circle, which indicates a 95% confidence interval around the mean score (Figure 2). The Marlborough region produces Sauvignon blanc wines that are significantly different ($p < 0.05$) than those from Hawke's Bay, Wairarapa, South Africa, France, Australia, United States, and Spain. These data suggest that N.Z. 2004 vintage wines had flavor profiles that were distinctive from those of the international wines. The sensory attributes on the left side of the x axis (CVA1) are apple, stone fruit, tropical, passion fruit skin/stalk, fresh asparagus, capsicum, sweet sweaty passion fruit, and cat urine/boxwood, whereas the right side is represented by bourbon and flinty. These are similar attributes to those expressed in PCA1 (Figure 1a, 1b). In PCA (Figure 1a), ellipses of the data from the Wairarapa

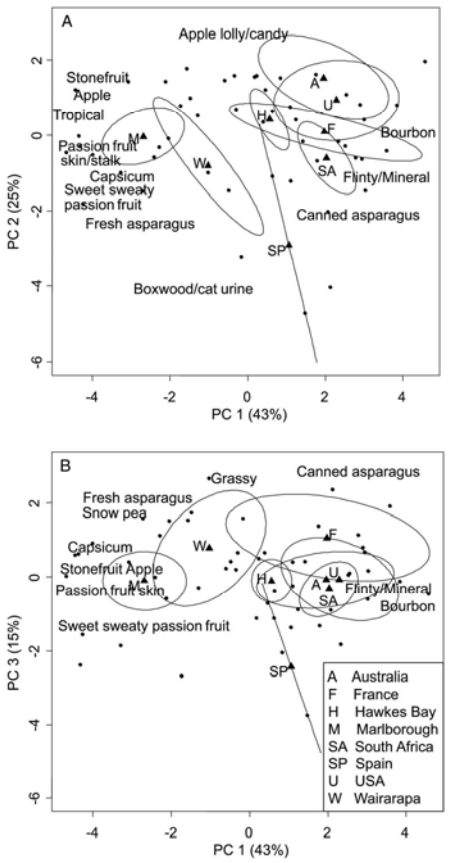

Figure 1 Principal component analysis of sensory data of Sauvignon blanc wines from five countries (**A**). Principal component analysis of sensory data of Sauvignon blanc wines from six countries and three New Zealand regions (PC1 vs PC3) (**B**). Means are represented by the corresponding letters for each country and ellipses represent 95% confidence limits surrounding the means.

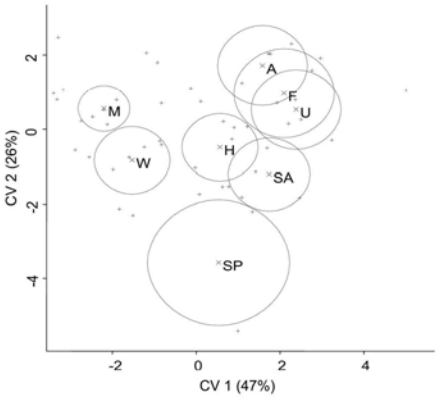

Figure 2 Canonical variate analysis (CVA) of sensory data of Sauvignon blanc wines from six countries. Means are represented by the corresponding letters for each country and ellipses represent 95% confidence limits surrounding the means.

and Marlborough regions overlap, but that is not the case for the means in CVA (Figure 2). These results occur because the PCA describes the similarities among the individual wines, whereas the CVA assesses differences among the regional means.

Aroma chemical analysis. Chemical analysis was conducted on 50 of the wines in this study (excluding the Spanish wines and one Hawke's Bay wine, and including a fifth French wine) (Table 4). Marlborough wines were significantly higher in 3MHA (sweet sweaty passion fruit) and 3MH (passion fruit skin/stalk) than wines from all other regions. Wairarapa wines were also high in 3MH and had even higher concentrations of MIBP (capsicum) than wines from other regions. The similarity of asparagus and MIBP green notes may explain the separation of Wairarapa wines, as seen in Figure 2. No differences were found in the concentrations of the MIPP (snow pea) attribute among the wines from the different regions. Although mean concentrations of 3MHA appear high for Marlborough (Table 4), the range in concentration values of 3MHA within the Marlborough wines was also wide, allowing for the possibility that specific wines within the region may indeed have had lower concentrations of 3MHA than wines from other regions.

Relationship between chemical and sensory data. Correlations ($r^2 > 0.50$) for each of three chemical flavor compounds (3MHA, 3MH, MIBP) with their respective sensory attributes are shown in Table 5. The concentration of these thiols can be used to predict the tropical characteristic of wine. The thiols (3MHA and 3MH) had the highest values for the coefficient of determination (tropical, sweet sweaty passion fruit, passion fruit skin/stalk, stone fruit). The tropical reference standard was highly correlated with two chemical compounds 3MHA ($r^2 = 0.80$) and 3MH ($r^2 = 0.65$). The sweet sweaty passion fruit attribute maintained a relatively high correlation ($r^2 = 0.73$) with 3MHA, which was the corresponding sensory reference standard (Table 2). These results support using the chemical measurement of 3MHA to predict the sensory perception of tropical and sweet sweaty passion fruit characteristics. The flavor

Table 5 Coefficient of determinations of 3-mercaptohexyl acetate (3MHA), 3-mercaptohexan-1-ol (3MH), and 2-methoxy-3-isobutylpyrazine (MIBP) and sensory attributes of Sauvignon blanc wines. Sensory attributes selected had higher than 0.50 in absolute values of coefficient of determination for the specific chemical (n = 50).

Descriptor	COD (n = 50)[a]
3MHA	
Tropical	0.80
Sweet sweaty passion fruit	0.73
Passion fruit skin/stalk	0.72
Stone fruit	0.57
3MH	
Passion fruit skin/stalk	0.63
Sweet sweaty passion fruit	0.55
MIBP	
Fresh asparagus	0.57
Bourbon	-0.54
Sweet sweaty passion fruit	0.53

[a]*p* value for the coefficient of determination <0.01 (n = 50).

Table 4 Concentrations of 2-methoxy-3-isobutylpyrazine (MIBP), 2-methoxy-3-methylpyrazine (MIPP), 3-mercaptohexyl acetate (3MHA), and 3-mercaptohexan-1-ol (3MH) in Sauvignon blanc wines sampled from different regions.

	Hawke's Bay	Wairarapa	Marlborough	Australia	South Africa	France	USA
MIBP (ng/L)							
Mean[a]	14.2[ab]	34.8[b]	22.0[b]	14.5[ab]	7.1[a]	7.9[a]	4.1[a]
Min.	8.9	25.6	12.6	10.1	3.5	4.8	<2.2
Max.	22.9	47.2	30.6	19.2	12.1	11.8	5.7
SD	6.1	8.9	5.9	3.9	4.0	3.6	1.7
MIPP (ng/L)							
Mean[a]	7.8[a]	9.5[a]	8.4[a]	11.9[a]	7.9[a]	8.1[a]	7.8[a]
Min.	7.0	8.1	6.3	10.8	6.3	6.0	7.4
Max.	8.3	11.2	11.4	13.7	9.1	9.7	8.2
SD	0.85	1.2	1.3	1.2	1.1	1.9	0.58
3MHA (ng/L)							
Mean[a]	66.0[a]	83.7[a]	485.8[b]	72.4[a]	50.0[a]	28.6[a]	45.1[a]
Min.	22.0	28.0	40.5	64.3	10.1	0.0	19.8
Max.	124.6	212.1	2507.0	78.1	119.2	83.4	62.6
SD	45.0	60.0	583.7	5.7	41.1	34.2	18.1
3MH (ng/L)							
Mean[a]	1733.1[a]	4210.0[b]	6604.1[c]	2379.4[ab]	1722.3[a]	2049.7[ab]	2094.4[ab]
Min.	925.0	1600.4	1477.6	1051.0	1013.0	687.7	860.2
Max.	3088.4	8733.3	18681.3	5241.0	2955.0	3053.8	4492.4
SD	765.0	2474.3	5285.2	1664.4	700.9	869.5	1628.4

[a]Means in the same row with different letters are significantly different ($\alpha = 0.05$).

compound 3MH showed a stronger relationship with the passion fruit skin/stalk attribute ($r^2 = 0.63$), which is the corresponding reference standard (Table 2). Measurement of the concentration of 3MH would predict the sensory perception of passion fruit skin/stalk but not as strongly as using the concentration of 3MHA to predict sweet sweaty passion fruit characteristic in the wine.

The green compound MIBP had the highest positive correlation with the fresh asparagus attribute at $r^2 = 0.57$ and the highest negative correlation with the bourbon attribute ($r^2 = -0.54$). Wines perceived as higher in capsicum, like those from Marlborough, were lower in the bourbon sensory attribute. The reverse was also true, with French wines higher in bourbon and lower in the capsicum sensory attributes. Regional wines that were high in the bourbon characteristics did not necessarily possess high alcohol content. For example, wines from Australia had the lowest mean alcohol at 10.6%, but were still perceived as having relatively high bourbon characteristics. Bourbon was described by panelists as being more of an earthy, smoky character rather than an alcoholic character.

The green compound MIBP had an even higher correlation with the fresh asparagus attribute ($r^2 = 0.57$) than with the capsicum attribute ($r^2 = 0.37$). Although 0.57 is not a high correlation, it does indicate some association with a green character. Wines having higher MIBP concentration will exhibit more fresh asparagus notes. The capsicum character was probably masked by the other components in the wine. Our results (Table 5) confirm other research that described the thiols as passion fruit descriptors (Tominaga et al. 1998, 2000) and that described MIBP as green (Allen and Lacey 1999).

The thiols (3MHA and 3MH) were highly correlated with their associated sensory attributes. These two thiols would serve as better predictors in modeling the sensory profile of wine than MIBP, which has a lower correlation with its sensory attribute, capsicum.

Partial least squares regression highlighted the relationship between the chemical analyses and the trained panel data (Figure 3). The two thiols were shown in close proximity to the sensory attributes tropical, passion fruit skin/stalk, and cat urine/boxwood, which are terms previously used to describe these thiols (Tominaga et al. 1998, 2000, Dubourdieu 2006, Lund et al. 2006). Boxwood has been used to describe high concentrations of 3MHA (Bouchilloux et al. 1998). **They** (the thiols?) may be in close proximity to cat urine/boxwood because 4-mercapto-4-methylpentan-2-one (4MMP) is in the same thiol chemical family. Researchers found that they strengthened their predictive model of Spanish red wines by grouping chemical families on the basis of their sensory and chemical analyses (Aznar et al. 2003). The current study confirms and supports these earlier studies with additional correlations of sensory attributes with chemical composition data.

Wine consumers. Of the 109 consumers, 100% were wine consumers (Table 6). The percentage of women (69%) was higher than the New Zealand percentage of women wine drinkers (55%) (Bruwer 2007). The majority of participants were New Zealanders (69%); other nationalities were Asian, Pacific Islander, European, Sri Lankan, Australian, Indian, and American, none comprising more than 15%. When asked about their white wine preferences and habits, consumers indicated they preferred and regularly drank Sauvignon blanc, followed by Chardonnay. Forty-one percent of the consumers primarily drank white wine, 20% drank predominately red wine, and 39% expressed no preference between red or white wine. When consumers were asked to list the wines they typically drank, 82% noted Sauvignon blanc, 64% noted Chardonnay, and 48% noted Riesling. These consumers (86%) typically spent (US$7.00 to 15.00) (NZ$10.00 to 20.00) on a bottle of wine.

After completing the demographic information and choice questionnaire, the consumers tasted the wines and rated their preference for each wine. The means and ANOVA of their preferences showed these consumers significantly preferred two of the wines from Marlborough compared to wines from Hawke's Bay, Australia, South Africa, France, and Wairarapa (Table 7). The two Marlborough wines had highest intensities of stone fruit, sweet sweaty passion fruit, cat urine, passion fruit skin/stalk, and tropical, as well as being lowest in bourbon and flinty. The least preferred wine (Wairarapa) possessed average intensities for all the attributes. The French and South African wines were high in mineral/flinty and bourbon characteristics. The Australian wine was highest in apple lolly and lowest in sweet sweaty passion fruit, capsicum, cat urine, passion fruit skin, and fresh asparagus characteristics. The Hawke's Bay wine was highest in bourbon and mineral/flinty but lowest in tropical, citrus, stone fruit, and apple characteristics.

An external preference map illustrated the sensory space of the wines in relationship to the consumer preference data, and a hierarchal cluster analysis identified

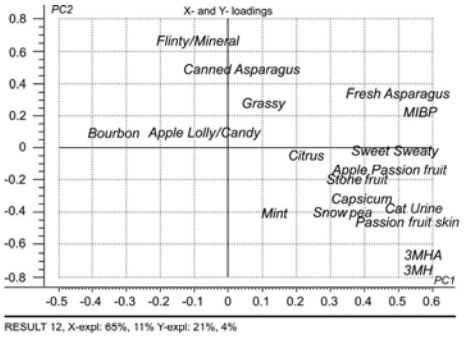

Figure 3 Partial least squares regression of sensory attributes and chemical flavor compounds of Sauvignon blanc wines.

groups of consumers and their preferences in relationship to the sensory data (Jaeger et al. 2003). A dendrogram from the cluster analysis identified two distinct groups of consumers (not shown). Cluster 1 indicated a consumer group that preferred a stone fruit, passion fruit skin/stalk, capsicum, sweet sweaty passion fruit, fresh asparagus, boxwood/cat urine-style Sauvignon blanc; whereas cluster 2 consumers preferred a Sauvignon blanc with bourbon as well as flinty/mineral characteristics. Cluster 1 comprised the largest portion of consumers (77%) surveyed and contained a larger percentage (53%) of respondents in the younger age brackets (<34 years) compared with cluster 2. Cluster 1 consumers were more likely to spend over $15 on a bottle of wine (54%) and to be New Zealanders (66%). Divorced people were primarily in cluster 2 and women dominated this cluster (four females to every one male). Eighty-four percent of cluster 1 normally drank Sauvignon blanc as their primary white wine, whereas there were only 68% in cluster 2 who normally drank Sauvignon blanc. Cluster 1 contained a higher percentage of white wine-only drinkers (43%) or those who drank both red and white wines (41%), compared with cluster 2, which had over twice as many red wine-only drinkers (36%).

Table 6 Demographic information from the New Zealand wine consumers (n = 109).

Demographic	Percent		Percent
Gender		**Wine preference**	
Female	69%	White	41%
Male	31%	Red	20%
Age		Both	39%
18–24	10%	Neither	0%
25–34	40%	**White wine preferences**	
35–44	23%	Sauvignon blanc	39%
45–54	18%	Chardonnay	26%
>55	9%	Riesling	12%
Status		Sparkling	8%
Single	22%	Gewürztraminer	6%
In relationship	9%	Pinot gris	6%
Couple living together	28%	White wine blend	1%
Married	34%	Other	0%
Divorced	3%	Do not like white wine	2%
Separated	2%	**White wine normally consumed**[a]	
Widowed	2%	Sauvignon blanc	82%
Wine consumption		Chardonnay	64%
Once a day	13%	Riesling	48%
3–4 times a week	44%	Sparkling	38%
Once a week	28%	Gewürztraminer	24%
Twice a month	10%	Pinot gris	39%
Once a month	5%	White wine blend	3%
Once a year	0%	Other	3%
Never	0%	Do not like white wine	3%
Main household shopper		**Average price spent on bottle**	
Yes	72%	<NZ$10	6%
No	28%	NZ$10 to NZ$14	43%
Income		NZ$15 to NZ$20	43%
<NZ$25,000	5%	NZ$21 to NZ$30	7%
NZ$25,001 to NZ$50,000	22%	NZ$31 to NZ$40	1%
NZ$50,001 to NZ$75,000	18%	**Ethnicity**	
NZ$75,001 to NZ$100,000	18%	New Zealand	70%
NZ$100,001 to NZ$150,000	28%	Asian	14%
>NZ$150,000	8%	European	6%
Not answered	1%	Australian	2%
		Pacific Island	1%
		Other	6%
		Not answered	1%

[a]Consumer was asked to check as many as applied.

Discussion

In past research, the Sauvignon blanc flavor profile has been attributed to methoxypyrazines (Allen and Lacey 1999), which give the wine green, capsicum characteristics. However, it has been noted that wines rarely have a sole "impact" compound, such as methoxypyrazine (Noble and Ebeler 2002). Using sensory, chemical, and consumer analyses, the current research determined that the 2004 Marlborough Sauvignon blanc possessed a distinctive and predictable flavor profile that the N.Z. consumers rated as most preferable.

The past literature has enumerated the many attributes associated with Sauvignon blanc wine (Allen and Lacey 1999, Lacey et al. 1991, Dubourdieu et al. 2006, Tominaga et al. 2000, 2006). These attributes (capsicum, grassy, passion fruit skin/stalk, sweet sweaty passion fruit, cat urine/boxwood) are characteristics that were also evident with the wines evaluated in this study. The strongest sensory attributes in Marlborough wines of this study were the high intensities of the fruity and green characteristics, such as tropical, sweet sweaty passion fruit, apple, stone fruit, capsicum, passion fruit skin/stalk, and fresh asparagus. The sensory attributes noted in the wines were highly correlated with the chemical measurements of thiol concentrations. Sensory attributes that contributed less strongly to the Marlborough style were mint, grassy, citrus, and snow pea. The sensory evaluation of snow pea intensities in the wines were confirmed by the chemical measurements of MIPP concentrations. Both analyses showed no significant differences among the wines.

In the sensory portion of this research, the 2004 Marlborough Sauvignon blanc wines not only had green characteristics (capsicum, passion

Table 7 Single factor analysis of variance of N.Z. consumer overall liking scores (n = 109) for eight Sauvignon blanc wines ($p < 0.05$). Fisher's least square differences were based on 95% confidence levels ($\alpha = 0.05$).

Region	Mean score[a]
Wairarapa	55.8[a]
France	62.4[ab]
South Africa	63. 3[ab]
Australia	63.5[b]
Hawke's Bay	64.0[b]
Marlborough 2	69.3[bc]
Marlborough 4	74.7[c]
Marlborough 7	75.7[c]

[a]Means in the same column with different letters are significantly different (LSD = 7.57, $p \leq 0.05$).

fruit skin/stalk, and fresh asparagus), but also high fruity characteristics (tropical, sweet sweaty passion fruit, apple, stone fruit). Statistical analysis of the sensory data (PCA and CVA) demonstrated that the 2004 N.Z. Sauvignon blanc had a distinctive flavor profile which was significantly different from the flavor profiles of the wines from France, Australia, South Africa, United States, and Spain. Although the French, U.S., and South African wines were quite similar, Australian wines were distinguished by their apple lolly/candy characteristic.

The French, South African, Australian, and U.S. Sauvignon blanc wines contained more mineral, flinty, and bourbon sensory characteristics. Analyzing the flavor compounds found in these international flavor profiles, such as 4-mercaptomethyl pentane for the cat urine/boxwood and benzyl methyl thiol for the flinty/mineral overtones (Tominaga et al 1998, 2000) could assist in creating an improved chemically based predictive model.

The chemical concentration of 3MHA and 3MH had higher means in Marlborough wines compared with those from other regions. These high concentrations showed a strong correlation with tropical sensory attributes. 3MHA had high correlation with the sweet sweaty passion fruit, and 3MH was correlated with passion fruit skin/stalk.

Capsicum is a characteristic commonly used to describe Sauvignon blanc, yet within this study MIBP had greater correlation with fresh asparagus than with capsicum. Further investigation might determine what other components could be masking the capsicum attributes in Marlborough Sauvignon blanc.

The sensory data from the 2004 vintage established that Marlborough and Wairarapa wines were somewhat similar, although the latter exhibited stronger asparagus notes. Similar to the results of the 2003 wines, the 2004 vintage from Hawke's Bay had the lowest concentrations of 3MHA, 3MH, and MIBP compared with the other two regions (Lund et al. 2005). The 2005 vintage has been examined to determine if there is continued consistency among the three vintages.

The Marlborough wines in this study had the highest levels of titratable acidity and residual sugar, the latter only significantly higher than wines from France and Spain. Interestingly, mean titratable acidity levels were significantly higher in all the New Zealand wines compared with the international wines. Increasing acidity is known to diminish perception of fruit characteristics, such as banana, in kiwifruit pulp (Marsh et al. 2006), and when sugar was added, the perception of fruit characteristics increased. Research predicted that an increase in sugar concentration would increase the headspace concentration of "fruity" volatiles in kiwifruit pulp, such as ethyl butanoate and (*E*)-2-hexanal (Friel et al. 2000). It might be valuable to measure the headspace of Marlborough wines and compare the results to wines with lower levels of titratable acidity and residual sugar.

The chemical data in this research supported the statement that Marlborough Sauvignon blanc wines have a complex style that is not influenced by a single "impact" compound (Noble and Ebeler 2002). There were higher concentrations of thiol (3MHA and 3MH) and methoxypyrazine (MIBP), which created some of the fruity and green characteristics.

The methoxypyrazine of Marlborough Sauvignon blanc has more of a fresh asparagus sensory attribute than a capsicum sensory attribute. Both the 3MHA and the MIBP were more closely associated with a natural product standard (tropical and asparagus, respectively) than with a single chemical as a reference standard (sweet sweaty passion fruit and capsicum, respectively.) The natural product reference standards may more successfully convey a complex sensory perception to a panelist. Perhaps a study evaluating the comparison of sensory reference standards comprised of solely chemical compounds versus reference standards comprised of solely natural products would be of interest in determining whether one set of standards indicates a better prediction of sensory attributes.

The low correlation between MIBP and capsicum character could be explained by a possible masking of MIBP by other components in the wine. Wine is a complex medium, in which many masking and synergistic interactions occur (Peinado et al. 2004). For example, 12% ethanol in water has an extremely strong smell, whereas at the same concentration in wine, the odor is greatly masked by other volatile compounds. Ethanol is capable of masking the perception of esters (Escudero et al. 2007). The negative correlation of the bourbon characteristic to the concentration of MIBP may suggest that there are sensory characteristics that are masked in the presence of compounds such as MIBP. Conversely, the capsicum characteristic may be explained by more than just the chemical concentration of MIBP. A study of sensory and chemical analyses of Spanish red wines found vegetal peppery characteristic to be correlated to isoacids, ethyl esters of isoacids, and fusel alcohol (Aznar et al. 2003). More chemicals will need to be measured and correlated with the sensory attributes to better understand the capsicum perception and the effect MIBP has on the perception of wine aroma.

The thiol and MIBP concentrations could be used to predict a Marlborough style, but it is apparent there are other sensory attributes to consider. Esters such as ethyl decanoate and ethyl hexanoate are also known to be present in Sauvignon blanc wines (Benkwitz et al. 2007). Other flavor compounds, such as esters and C6 compounds, should be measured since they contribute to fruity and green characteristics in wines. Such investigations would enable a more predictive model to be used in anticipating sensory attributes. Studies evaluating synergistic and masking effects of a wider range of chemical compounds would also help in understanding the complex attributes found in wine.

Although there were differences between the wines that could be measured through chemical analyses and sensory evaluation, from a commercial point of view the ultimate consideration is whether the average wine consumer could perceive a difference. Price is less of a dominant predictor of purchasing behavior as wine consumers are becoming more interested in other aspects of wine. Regional reputations are beginning to play a bigger role for the "highly product involved," more knowledgeable wine consumer (Schamel 2006, Tustin and Lockshin 2001). Consumers in this study preferred wines that presented sweet sweaty passion fruit, capsicum, passion fruit skin/stalk, and fresh asparagus overtones. These results would suggest that N.Z. consumers could recognize and prefer the Marlborough Sauvignon blanc style. One Spanish study found local wines were preferred by locals and purchased on that basis (Martinez-Carrasco et al. 2005). A Spanish consumer study determined that wine origin was more important than price and vintage in influencing consumer selection (Sanchez and Gil 1997). The authors found that while rural consumers desired local wines, urban consumers preferred the perceived higher prestige of wines from the Rioja region, indicating that effects of regionality on consumer behavior are broader than consideration of a wine's sensory characteristics.

New Zealand wine consumers significantly preferred the unique sensory attributes found in Marlborough Sauvignon blanc wine. These consumers were familiar with Sauvignon blanc, as evident in the cluster analysis results identifying the frequency and selection preferences of their purchasing behavior. The consumers in cluster 1 chose Sauvignon blanc as their most purchased and preferred white wine. In contrast, cluster 2 preferred the flinty, mineral profile of the international wines. Interestingly, cluster 2 had a greater percentage (44%) of non-New Zealanders while cluster 1 had 23%. The research design did not include any determination of how long the non-New Zealander panelists had been residing in New Zealand or the extent of their wine consumption behaviors prior to their arrival. Without this knowledge, only limited conjecture can be made as to whether a limited familiarity with Marlborough Sauvignon blanc may be influencing their wine preference choices. Cluster 2, with more non-New Zealanders, consumed less wine compared to New Zealanders. Sixty-five percent of New Zealanders in the current study consumed wine three or more times per week, whereas only 33% of non-New Zealanders were consuming wine that frequently. Higher wine consumption might infer that these consumers have a greater familiarity with Marlborough Sauvignon blanc and therefore a greater preference, as in the Spanish study (Martinez-Carrasco et al 2005).

According to one study, Australian and New Zealand consumers are increasingly preferring cool-climate wines such as Sauvignon blanc (Schamel and Anderson 2003). Other export markets may not show the same trend in wine preferences. Determining whether international consumers share this cool-climate wine preference will be important to the N.Z. wine export industry. Subsequent investigation of more recent vintages will be important in confirming whether N.Z. Sauvignon blanc is distinct and distinguishable from other regional Sauvignon blanc wines.

Conclusion

Results from sensory analysis, chemical analysis, and New Zealand consumer preference data substantiate the claim that when consumers receive a Marlborough Sauvignon blanc wine, it exhibits distinctive flavors. The 2004 vintage showed significant differences between Marlborough New Zealand and international Sauvignon blanc wines tested in this study. More international wines should be analyzed and tested to confirm these results. Regional differences were also apparent within New Zealand, especially between Hawke's Bay and Marlborough wines. Wairarapa wines, although similar to those from Marlborough, contained more green characteristics, and consumer data suggested a preference for Marlborough wines. Chemical analysis data showed strong correlations of three chemicals (3MHA, 3MH, MIBP) with some of the sensory attributes. In comparison to methoxypyrazine, the thiols showed higher correlations with the sensory attributes. Investigating the effects of flavor compound masking/synergism may contribute to a more authentic representation of the Sauvignon blanc flavor profile. Lastly, consumers within New Zealand preferred Marlborough Sauvignon blanc to international Sauvignon blanc wines tested in this study. A greater number of international wines should be analyzed and tested to confirm these results.

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Appendix L: PUBLICATION OF CHAPTER 4

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Effect of polyphenols on the perception of key aroma compounds from Sauvignon Blanc wine

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Abstract

Background and Aims: Sensory wine research has mainly focused on the role of volatile compounds and their contribution to the aroma profile. Wines also contain polyphenolic compounds, which are not volatile. This research begins to investigate the interactions of volatile and non-volatile wine compounds and the consequential effects on sensory perception of aroma.

Methods and Results: Trained panellists of this study measured the perception of four aroma compounds (isobutyl methoxypyrazine, 3-mercaptohexanol (3MH), 3-mercaptohexanol acetate and ethyl decanoate) in wine. Panellists assessed the four compounds in combinations with three polyphenols (catechin, caffeic acid and quercetin) commonly found in white wine. The perception of isobutyl methoxypyrazine, 3MH and ethyl decanoate was largely suppressed by the added polyphenols, while the perception of 3MH was accentuated with the addition of caffeic acid. Of the three polyphenols, only catechin had a slight effect of accentuating the mercaptohexanol acetate perception.

Conclusions: Results showed each polyphenol had a unique effect when blended with a specific aroma compound, either suppressing, accentuating or showing little effect on the perception of the aroma compounds.

Significance of the Study: Understanding these interactions can assist winemakers in managing polyphenol levels to optimize selected volatile compounds to achieve desirable aroma profiles.

Keywords: *methoxypyrazines, perception, polyphenols, Sauvignon Blanc wine, thiols*

Introduction

Sauvignon Blanc key aroma compounds

Wine critics initially recognize Sauvignon Blanc for its green herbaceous characteristics (Cooper 2002). Key odour compounds contributing to the distinctive flavour profile of Sauvignon Blanc include methoxypyrazines (e.g. isobutyl methylpyrazine (IBMP)) and thiols (e.g. 3-mercaptohexanol (3MH) and 3-mercaptohexyl acetate (3MHA)) (Lund et al. 2008). Previous research suggested that IBMP, with its distinctive green capsicum note, is a contributor to the herbaceous character of Sauvignon Blanc wine (Allen and Lacey 1999). Another herbaceous aroma characteristic in Sauvignon Blanc wine has been described by a sensory panel as passionfruit skin/stalk (Lund et al. 2008), and is found to derive from the thiol compound 3MH. Tominaga et al. (1998) extensively studied thiols and their contribution to Sauvignon Blanc aroma, specifically that yeasts metabolize the thiol precursors to produce aromatic thiols.

It is interesting to note that both 3MHA and 3MH compounds have been found in significantly higher quantities in Marlborough, New Zealand Sauvignon Blanc than can be found in either Sauvignon Blanc wines from other New Zealand wine regions, or from Sauvignon Blanc wines from other countries (Lund et al. 2008). In that same study, the panellists described the 3MHA aroma as sweet sweaty/passionfruit. Tominaga et al. (2000) found that 3MHA has a lower sensory perception threshold concentration than 3MH in both water and wine media. Based on the high concentration of 3MHA in Marlborough Sauvignon Blanc, this finding suggests that 3MHA may contribute a stronger sensory impact on New Zealand Sauvignon Blanc wine than 3MH.

Esters are also major contributors to Sauvignon Blanc wine (Benkwitz et al. 2007). A sensory panel described ester characteristics as banana lolly (amyl acetate), herb floral (ethyl octanoate) and honey mead (ethyl decanoate) (Lund et al. 2007).

Sauvignon Blanc polyphenols

As with many white wines, Sauvignon Blanc primarily contains three types of polyphenols, the flavan-3-ols, hydroxycinnamic acids (as tartrate esters in grapes) and flavonols (glycoside forms in grapes), which can be

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represented by the common monomeric compounds catechin, caffeic acid and quercetin, respectively. The concentration of these compounds in Sauvignon Blanc wines can reach 10 mg/L for catechin (and epicatechin), 100 mg/L for caffeic acid and related hydroxycinnamic acids, and 10 mg/L for quercetin and its glycosides (Frankel et al. 1995, Maggu et al. 2007).

There has been very little sensory research examining the role of white wine polyphenolic compounds on the perception of wine aroma. Most of the sensory research of wine polyphenolic compounds has focused on the perception of mouthfeel and taste. For instance, a number of studies have assessed sensory measurements of astringency and/or bitterness in red wine polyphenols. (Robichaud and Noble 1990, Lawless et al. 1994, Gawel et al. 2000, 2001, 2007, Francis et al. 2002, Monteleone et al. 2004, Tao et al. 2007). A large molecule, such as a polyphenol, is too massive to be perceived by the olfactory system. Molecules with molecular weights over 300–400 Da do not have the capacity to reach the olfactory receptors in the human nose (Jacob 2005).

The research that has been conducted on red wine polyphenols in relation to aroma compounds is limited to chemical measurements of aromatic esters rather than the sensory perception of the aroma compounds (Dufour and Sauvaitre 2000). Only one research project has evaluated the sensory effects of polyphenols (gallic acid and naringin) on the intensity of perception of aroma compounds (2-methylpyrazine and ethyl benzoate) in water and wine matrices (Aronson and Ebeler 2004). In that study, the two polyphenols were found to suppress both of the aroma compounds when combined singularly in water matrices. However, when the polyphenols and aroma compounds were combined in the wine matrices (Chardonnay and Cabernet Sauvignon), the sensory analyses were not statistically significant, even though chemical headspace analysis determined a significant reduction in the concentration of aroma compounds. The authors attributed these inconclusive sensory results to insufficient panellist training, and there being an existing presence of tannins that might lend itself to no further measurable effects.

The current study was designed to continue investigating the effects of polyphenols on aroma perception. Building on the foundation of Aronson and Ebeler's research, the current research increased the depth of sensory panel training before attempting any perception measurements.

Measurement of perception of Sauvignon Blanc aroma compounds

Because this study was aimed at determining whether well-trained panellists could detect any perceivable differences in Sauvignon Blanc aroma compounds as a result of varying levels of polyphenols, a difference test was identified as the appropriate method (Lawless and Heymann 1999). The *R*-index methodology has commonly been used in sensory and consumer research to measure product variation (O'Mahony and Rousseau 2003). The *R*-index can be used to determine when a human can perceive a difference between two concentrations of a volatile compound. One sample would have no added amount of the volatile compound (which is referred to as the noise), while the other sample (the signal) would have an added amount. Bi and O'Mahony (1995) used this methodology to measure the difference between cookies made with two different concentrations of sugar. Their objective was to determine the lowest difference in sugar concentration at which a panellist could still perceive a difference from the original cookie formula. This *R*-index methodology was used in this study.

The main research objective of this study was to investigate the sensorial aroma effects that polyphenolic compounds induced on key odour compounds found in New Zealand Sauvignon Blanc wine.

Materials and methods

Sample preparation

A non-Sauvignon Blanc white wine (N.V. Chasseur dry white table wine) was used for the experiment. This wine was diluted by 50% with Microlene™ filtered water and was referred as the 'diluted base wine'. The justifications for diluting the wine are explained below. The base wine had a pH of 3.20 (±0.10), 6.25 (±0.35)% ethanol (v/v), 4.0 (±1.0) g/L residual sugar and 3.25 (±0.15) g/L titratable acidity.

The diluted base wine was chemically analysed for the thiols and methoxypyrazine by GC-MS using a procedure reported in Brajkovich et al. (2005) and Lund et al. (2008), respectively. The diluted base wine was found to have 538 (±28) ng/L of 3MH. IBMP, 3MHA and ethyl decanoate were not detected in the diluted base wine. The detection limits of the analytical methods, calculated using IUPAC methodology were 1 ng/L for IBMP, 25 ng/L for 3MH and 8 ng/L for 3MHA (Currie 1995).

The quantification of the ester, ethyl decanoate, was as follows. A triple extraction (4:2:2 mL) with 1:1 diethylether : hexane was undertaken on 50 mL of sample spiked with 25 µL of octan-3-ol (920 mg/L, in absolute ethanol) as internal standard. The organic phase was dried using anhydrous sodium sulfate and concentrated down to 100 µL under nitrogen flow. Two µL were analysed by gas chromatography (Agilent 6890N) using a capillary column, HP-Innowax (60 m × 0.252 mm × 0.25 µm). The splitless injection port was heated to 230°C, and the split vent was opened after 1 min. The carrier gas was helium, and the pressure was 109 kPa. The initial oven temperature was 40°C (for 10 min) then ramped at 6°C/min to 170°C, further raised to 240°C and held for 10 min. The GC was coupled to an Agilent 5973 mass selective detector. The interface temperature was kept at 230°C, and the ion source was working in EI mode at 70 eV. The quadrupole temperature was set at 150°C. The analysis was performed in SIM mode. The ions 70, 88 and 101 *m/z* were selected for ethyl decanoate (70 *m/z* was used for quantification), and the ions 59, 83 and 101 *m/z* were selected for the internal standard (59 *m/z* was used for quantification). The standard curve was

Table 1. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of IBMP using *R*-index difference testing (bolded rows are the lowest concentrations of a perceivable difference)

Polyphenol in both noise and signal	Polyphenol amount (mg/L)	IBMP in noise† (ng/L)	IBMP in signal‡ (ng/L)	Difference of noise and signal (ng/L)	*R*-index§	Significantly different
None	0	0	8.5	8.5	0.607	No
None	**0**	**0**	**17**	**17**	**0.860**	**Yes¶**
Catechin	12	0	17	17	0.693	No
Catechin	12	0	34	34	0.417	No
Catechin	12	0	68	68	0.527	No
Catechin	12	0	80	80	0.544	No
Catechin	12	0	160	160	0.678	No
Catechin	**12**	**0**	**175**	**175**	**0.709**	**Yes**
Caffeic acid	102	0	17	17	0.607	No
Caffeic acid	102	0	34	34	0.633	No
Caffeic acid	102	0	68	68	0.664	No
Caffeic acid	102	0	80	80	0.489	No
Caffeic acid	102	0	160	160	0.567	No
Caffeic acid	**102**	**0**	**175**	**175**	**0.760**	**Yes**
Quercetin	**10**	**0**	**17**	**17**	**0.760**	**Yes**

†Noise (background) was defined as the diluted wine base with no IBMP added.
‡Signal was defined as the diluted wine base with IBMP added.
§*R*-index critical = 0.691 for $n = 15$, unless otherwise stated ($P = 0.025$).
¶*R*-index critical = 0.696 for $n = 14$, ($P = 0.025$). IBMP, isobutyl methoxypyrazine.

prepared by adding increasing quantities of ethyl decanoate to a wine to obtain six different concentrations from 50 to 300 µg/L. The regression equation obtained was $y = 2.8318\times - 0.0533$ with $r^2 = 0.99$. An average relative standard deviation of 12.2% was obtained during a survey of 50 Sauvignon Blanc wines analysed in triplicate.

The concentration of polyphenols ($n = 3$) in the diluted base wine were determined at 1.84 (±0.17) mg/L for catechin, and 2.30 (±0.08) mg/L for caffeic acid, while no quercetin was detected, using a reverse phase HPLC method reported elsewhere (Brajkovich et al. 2005, Tao et al. 2007). The concentrations of the polyphenols in the diluted base wine were increased by 10 mg/L (catechin and quercetin) or 100 mg/L (caffeic acid) such that the values listed in Tables 1–4 are the sum of the added and naturally occurring polyphenols.

Polyphenols, catechin (Sigma), caffeic acid (Sigma), and quercetin (Sigma) were weighed on an analytical balance and dissolved in ethanol (99% purity, Sigma). One mL polyphenol mixture at the appropriate concentration was added to a litre of diluted base wine.

Standard stock solutions of the methoxypyrazine and thiols were prepared. IBMP (Acros Organics) and 3MH (Interchim), 3MHA (Oxford Chemical) were diluted to the following concentration for stock solutions: IMBP = 245 µg/µL, 3MHA = 344 ng/µL, 3MH = 226.5 ng/µL with ethanol (Sigma). These stock solutions (1–30 µL) were diluted to the appropriate concentration on the day of testing and added to a litre of diluted base wine with the appropriate polyphenol. Stock solutions were protected from the light and stored at −20°C until the day of assessment. IBMP was wrapped in foil to protect from light degradation. Ethyl decanoate (Aldrich) was added directly to a litre of diluted base wine to the appropriate concentration listed in Table 4.

Sensory panel

Fifteen trained panellists experienced in tasting Sauvignon Blanc were used to evaluate the polyphenols and key Sauvignon Blanc flavour compounds. The panel ages ranged from 25 to 53 years. The evaluation was performed at HortResearch's Sensory and Consumer Science facility in Mt Albert, Auckland, New Zealand. Evaluations were conducted in booths with green lighting and positive airflow to reduce any biases from colour or non-product odours. Assessments occurred between 11 a.m. and 12 p.m., 4 days a week. The samples were served in standard XL wine glasses with watch glass lids. Wine glasses were labelled with three digit random number codes and 10 mL of sample was aliquotted into each wine glass. Samples were prepared 1 h prior and served at room temperature (20°C). Panellists evaluated the samples orthonasally in a specified, randomised order (see below). Panellists were instructed to smell water between sample pairs. They were given a 5-min break after evaluating a set of four paired samples, with a maximum of 12 paired samples evaluated at each session. The panellists were never given information about the samples. Panellists also were never given their results to prevent them from exhibiting learned behaviours. Difference testing data was collected on a paper ballot.

Table 2. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of 3MH using *R*-index difference testing (bolded rows are the lowest concentrations of a perceivable difference).

Polyphenol in both noise and signal	Polyphenol amount (mg/L)	3MH in noise† (ng/L)	3MH in signal‡ (ng/L)	Difference of noise and signal (ng/L)	*R*-index§	Significantly different
None	0	538	2038	1500	0.597¶	No
None	**0**	**538**	**2288**	**1750**	**0.806††**	**Yes**
Catechin	12	538	2288	1750	0.560	No
Catechin	12	538	2538	2000	0.640	No
Catechin	**12**	**538**	**3538**	**3000**	**0.720**	**Yes**
Caffeic acid	102	538	1788	1250	0.530	No
Caffeic acid	**102**	**538**	**2038**	**1500**	**0.728**	**Yes**
Caffeic acid	102	538	2288	1750	0.960	Yes
Quercetin	10	538	2288	1750	0.518	No
Quercetin	10	538	2538	2000	0.493	No
Quercetin	10	538	3538	3000	0.682	No
Quercetin	**10**	**538**	**4538**	**5000**	**0.904**	**Yes**

†Noise (background) was defined as the diluted wine base with no 3MH added.
‡Signal was defined as the diluted wine base with 3MH added.
§*R*-index critical = 0.691 for $n = 15$, unless otherwise stated ($P = 0.025$).
¶*R*-index values obtained on three other occasions: 0.398, 0.458, 0.704 – the last when the *R*-index critical value was 0.708.
††*R*-index values obtained on one other occasion: 0.802. 3MH, 3-mercaptohexanol.

Table 3. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of 3MHA using *R*-index difference testing (bolded rows are the lowest concentrations of a perceivable difference).

Polyphenol in both noise and signal	Polyphenol amount (mg/L)	3MHA in noise† (ng/L)	3MHA in signal‡ (ng/L)	Difference of noise and signal (ng/L)	*R*-index§	Significantly different
None	0	0	150	150	0.508¶	No††
None	**0**	**0**	**200**	**200**	**0.742‡‡**	**Yes**
Catechin	12	0	75	75	0.471	No
Catechin	**12**	**0**	**150**	**150**	**0.707**	**Yes**
Catechin	12	0	200	200	0.793	Yes
Caffeic acid	102	0	150	150	0.636	No
Caffeic acid	**102**	**0**	**200**	**200**	**0.820**	**Yes**
Quercetin	10	0	150	150	0.587	No
Quercetin	**10**	**0**	**200**	**200**	**0.822**	**Yes**

†Noise (background) was defined as the diluted wine base with no 3MHA added.
‡Signal was defined as the diluted wine base with 3MHA added.
§*R*-index critical = 0.691 for $n = 15$, unless otherwise stated ($P = 0.025$).
¶*R*-index values obtained on two other occasions: 0.535, 0.543.
††*R*-index critical = 0.696 for $n = 14$, ($P = 0.025$).
‡‡*R*-index values obtained on one other occasion: 0.766. 3MHA, 3-mercaptohexanol acetate.

Difference testing and data analysis

The difference test employed to measure the impact of polyphenols on sensory perception was the *R*-index methodology outlined in Bi and O'Mahony (1995). The lowest concentrations at which the panellists could perceive a difference (sensory perception threshold) were determined for these volatile compounds with no added polyphenols. Subsequently, these lowest concentration values were then compared with values obtained after the polyphenol compounds were added to test for a resultant suppression or synergistic effect.

The coded pairs were presented in a balanced design, with each person receiving four paired samples in all combinations (AB, BA, BB and AA). The noise sample ('A') contained the polyphenol being tested in a diluted base wine, and the signal sample ('B') contained the polyphenol being tested plus a predetermined amount of a volatile aroma compound in a diluted base wine. The

Table 4. Effects of polyphenols (catechin, caffeic acid, and quercetin plus putative degradation products) on the perception of ethyl decanoate using *R*-index difference testing (bolded rows are the lowest concentrations of a perceivable difference).

Polyphenol in both noise and signal	Polyphenol amount (mg/L)	Ethyl decanoate in noise† (µg/L)	Ethyl decanoate in signal‡ (µg/L)	Difference of noise and signal (µg/L)	*R*-index§	Significantly different
None	0	0	600	600	0.640	No
None	**0**	**0**	**750**	**750**	**0.791**	**Yes**
Catechin	12	0	1000	1000	0.687	No
Catechin	**12**	**0**	**2000**	**2000**	**0.787**	**Yes**
Caffeic acid	102	0	1000	1000	0.647	No
Caffeic acid	**102**	**0**	**2000**	**2000**	**0.844**	**Yes**
Quercetin	10	0	750	750	0.660	No
Quercetin	**10**	**0**	**1000**	**1000**	**0.747**	**Yes**

†Noise (background) was defined as the diluted wine base with no ethyl decanoate added.
‡Signal was defined as the diluted wine base with ethyl decanoate added.
§*R*-index critical = 0.691 for $n = 15$, unless otherwise stated ($P = 0.025$).

panellists were asked whether pairs were the 'same' or 'different' and whether they were 'sure' or 'unsure'. *R*-index (R_i) values were calculated, and R_i-50% results were compared with *R* critical value for a one-tailed test at a 2.5% significance level that the result is greater than the probability of chance. The critical value was found to be 19.1% for $n = 15$ (or 0.691) using the table in Bi and O'Mahony (2007).

Results and discussion

Perception of difference threshold

The lowest concentration at which the panel could perceive a significant difference for any increase in the concentration of the aroma compound over naturally occurring amounts is shown (Tables 1–4). At concentrations below these values, the panel could not perceive a significant difference between the not supplemented diluted base wine (containing the indicated amounts of naturally occurring aroma compound) and the supplemented diluted base wine. To ensure the validity of these base values, the results for the volatile thiols 3MH and 3MHA were retested with the panel two to three times over the span of a year.

These difference thresholds were closely related to the discrimination threshold, but differed in that they were dependent on the background matrix in which the tests were undertaken – in this case, the 'diluted based wine' contained measurable levels of some of the aromas (see below).

The effect of polyphenols was assessed for each aroma compound by comparing the difference thresholds values obtained in the presence or absence of the added polyphenol. The effects of the polyphenol were then classed as 'suppressing' or 'accentuating', depending on whether the difference thresholds value increased or decreased when the polyphenols were added.

While there was no measurable IBMP, 3MHA or ethyl decanoate in the diluted base wine, there was 538 ng/L of 3MH present. Although it would be desirable to start with a complete absence of the aroma compounds, it was considered to be more important to carry out the experiments within a realistic wine matrix. Our previous research had demonstrated that single thiols in water were more difficult for panellists to consistently measure perception because of thiol high volatility. Attempts to use a model wine (ethanol, sugar, tartaric acid plus aroma compounds) resulted in high levels of panellist fatigue from the ethanol. Ethanol has been demonstrated to mask volatile compounds, such as esters (Escudero et al. 2007). This masking should be considered when assessing perception. Future studies might include the assessment of compounds in water only to determine if the absence of ethanol affects the perception. Ferreira et al. (2007) recommended the use of a base wine medium for aroma analysis to more closely simulate a real wine scenario. In the present research, the panel evaluated samples using a base wine, which had some ethanol and a similar pH to that normally present in wine. This would simulate a real wine scenario in which these volatile compounds would normally be perceived.

The catechin concentration mean and standard deviation in the samples was 11.9 ± 2.5 mg/L, while the caffeic acid samples were 92 ± 15 mg/L. The quercetin concentration was not detected even though an addition to 10 mg/L was made, indicating that the free quercetin had degraded over 2–3 h between making up the solutions and running the analysis by HPLC. The results shown by the addition of quercetin will need to be examined in a future study using a glycosidic quercetin derivative (e.g. rutin) to confirm that flavonols in wine are responsible for perception effects.

Polyphenol effects on IBMP

Table 1 shows that the perception of IBMP was suppressed by both catechin and caffeic acid, and somewhat by quercetin or its degradation products. A 'significant' result (*R*-index value > 0.691) for the perception of IBMP was achieved when 17 ng/L IBMP was added to the

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diluted base wine. At the concentrations used in this experiment, catechin and caffeic acid had a higher suppression ability than added quercetin, which had no effect. However when a total of either 12 mg/L of catechin or 102 mg/L of caffeic acid was present in the diluted base wine, the addition of IBMP to 175 ng/L was required before panellists perceived a difference. The average IBMP concentration found in New Zealand Sauvignon Blanc in one survey was 23 ng/L, with a range from 9 to 47 ng/L (Lund et al. 2008). This represents a 10-fold increase in IBMP concentration compared with the panel's IBMP discrimination threshold, and raises issues whether IBMP alone is responsible for a perceived capsicum aroma. This observation would also explain data from Lund et al. (2008), which showed a low coefficient of determination of 0.37 between the chemical concentration of IBMP in 50 Sauvignon Blanc wines from around the world, and the sensory panel's perception of the green capsicum attribute, whose reference standard was IBMP. Such effects were also noted in a study by Marais et al. (1998), in which it was found that the higher levels of IBMP in different South Africa regional wines did not necessarily correlate with the capsicum perception of these wines.

The mechanism by which the non-volatile polyphenols suppress perception of IBMP is not known. One suggestion is that the large number of –OH groups on these polyphenols may form reasonably strong, although temporary, non-covalent bonds with the methoxypyrazine, thus lowering its volatility in the headspace above the wine. These non-covalent bonds could involve interactions such as π–π, hydrophobic and hydrogen bonding (Dufour and Bayonove 1999, Jung et al. 2000). Conversely, the carbonyl group on the flavonol quercetin or quercetin degradation products may be less effective in interacting with IBMP than catechin.

Polyphenol effects on 3MH

The perception of the 3MH aroma compound (described as 'passionfruit skin/stalk') was affected by the addition of polyphenols to different degrees. Before adding polyphenols, 3MH was perceived at 1750 ng/L but not at 1500 ng/L (Table 2), a result confirmed on three separate occasions. When 10 mg/L of catechin was added, the 3MH required an increase to 3000 ng/L before a difference was perceived. When 10 mg/L of quercetin was added, an even stronger suppression effect was observed, where the 3MH required an increase to 5000 ng/L before any difference was perceived. These increases in perception thresholds suggest that the aroma compounds were interacting with the polyphenols.

Adding caffeic acid to the 3MH aroma compound showed the opposite effect. 3MH was perceived at a lower concentration of 1500 ng/L, below the previously determined difference threshold value of 1750 ng/L. This result suggests that caffeic acid may have suppressed other aroma compounds in the diluted base wine that initially masked the 3MH aroma. Once the caffeic acid binds to these 3MH suppression compounds, the perception of 3MH becomes accentuated.

In contrast with the accentuation effects from caffeic acid, the suppression effects of catechin and quercetin might play a more dominant role in the aroma profile of Sauvignon Blanc wine. The 3MH concentrations of New Zealand Sauvignon Blanc have been found to vary between 900 and 18 000 ng/L, with a mean value of 5000 ng/L (Lund et al. 2008). As any observed suppressions of aroma were occurring at levels well below the high 3MH concentrations found in New Zealand Sauvignon Blanc, these suppression effects may be more important for the perceived aromas of Sauvignon Blanc wines from other countries, where 3MH concentrations have been measured at lower averages of approximately 2000 ng/L (Lund et al. 2008).

Chemical concentrations can be used to predict sensory attributes. In a previous study correlating the sensory panel perceptions of 3MH to the chemical measurement of 3MH in 50 international Sauvignon Blanc wines, the coefficient of determination was found to be 0.63 (Lund et al. 2008). This would indicate that the 3MH in these wines was moderately perceivable.

Polyphenol effects on 3MHA

With no additional polyphenols included in the diluted base wine, the panellists perceived added 3MHA at 200 ng/L, but not at 150 ng/L (Table 3), which was also confirmed on three separate occasions. When catechin was added to the diluted base wine, panellists could perceive 3MHA at 150 ng/L. 3MHA is a key flavour contributor to New Zealand Sauvignon Blanc that was only slightly affected by the addition of three polyphenols.

Our past research showed a high correlation between sensory attribute measurements and the corresponding 3MHA thiol concentration (Lund et al. 2008), with a coefficient of determination of 0.73 between 3MHA concentrations and the sweet sweaty passionfruit sensory attribute (reference standard = 3MHA). The aroma perception of 3MHA was also the least affected by added polyphenols in comparison with the other aroma compounds in the present study. The structure of 3MHA differs from 3MH in that the –OH has been esterified with acetic acid, and making the ester form less likely to interact with a polyphenol. The lack of suppression by the polyphenols and the higher concentration of 3MHA in New Zealand Sauvignon Blanc wines demonstrates the crucial role 3MHA plays in the flavour of New Zealand Sauvignon Blanc. Also important to note is that 3MHA has a perception threshold in water of 2–20 ng/L, while 3MH is higher at 60 ng/L (Tominaga et al. 1998).

Polyphenol effects on ethyl decanoate

Ethyl decanoate, a typical wine ethyl ester, was defined by a sensory panel as honey mead (Lund et al. 2007). The perception of ethyl decanoate was reduced by all three of the polyphenols (Table 4). All of the polyphenols consistently suppressed the panellists' perception of the ester, although caffeic acid and catechin seemed to have a slightly greater effect. This finding corroborates previous research on esters by Aronson and Ebeler (2004), which showed that gallic acid minimises the sensory perception

of the ester, ethyl benzoate. In that study, the esters were interpreted as being bound to the polyphenols, thus reducing the panellists' perception of them.

Aronson and Ebeler (2004) found that polyphenols produced a greater reduction in the GC peak areas of long chain esters. For example, when a polyphenol was combined with ethyl hexanoate (C6) versus ethyl octanoate (C8) versus ethyl decanoate (C10), the reduction of the GC peak area was greatest with ethyl decanoate, which was the longest chain ester. The authors' plan for future research will include an examination of the correlation of GC headspace analysis and sensory data for other esters present in Sauvignon Blanc wine.

Volatiles and polyphenols

While astringency and mouthfeel have dominated much of the past research on polyphenols in wine, their interaction with the volatile compounds remains to be explored in more depth. This research supported findings from previous sensory studies and found a similar increase in the suppression effect of specific Sauvignon Blanc aroma compounds in conjunction with their decreased degree of correlation of sensory attribute intensities and chemical concentrations (Lund et al. 2008). In this case, the influence of variable levels of polyphenols in commercial wines will lead to different suppression effects on the aroma compounds present. For example, with a high coefficient of determination for 3MHA ($r^2 = 0.73$), there were minimal suppression effects on the perception of 3MHA when polyphenols were added. With a moderate coefficient of determination for 3MH ($r^2 = 0.63$), there was some suppression with catechin and quercetin additions and some accentuating effects on the perception of 3MH with caffeic acid additions. The lowest coefficient of determination ($r^2 = 0.37$) for IBMP had the most severe suppression effects with catechin and caffeic acid additions, and, to a lesser extent, with quercetin additions. Each of the polyphenols reacted uniquely with each specific aroma compound. Of the three polyphenols, catechin, showed the greatest suppression on three aroma compounds, but it had a slight accentuation effect on 3MHA perception. The suppression of these volatile compounds in a wine matrix is not solely caused by polyphenols, but other compound present in the wine matrix. For example, Escudero et al. (2007) found that ethanol masks ester compounds in red wine.

A recent study reported that polyphenols, such as the hydroxycinnamic acids (e.g. caftaric acid), are present at higher concentrations in free run Sauvignon Blanc juice, with little or no catechin or flavonols present (Maggu et al. 2007). In the same study, Sauvignon Blanc juice made using prolonged skin contact and pressure contained minimal hydroxycinnammic acids, but significant levels of quercetin-3-glucoside (10 mg/L) (Maggu et al. 2007). If more seeds and skins were left in the presence of juice, more catechin and quercetin glycosides would be extracted. Given the suppression seen of 3MH perception because of flavonoids such as catechin, but not seen with caffeic acid, the use of free-run juice is likely to accentuate the passionfruit skin/stalk character in Sauvignon Blanc wine.

Winemaking practices, such as the use of oak to ferment or store wine, can introduce different polyphenols into the wine. Ibern-Gomez et al. (2001) reported that oak increases the concentration of polyphenols. Understanding the effects of polyphenols on aroma perception can be used to create desired flavour profiles. Further research into different polyphenol concentrations and their suppression effects on aroma compound perceptions needs to be conducted. This study begins the exploration of sensory perception of interactions with non-volatile and volatile compounds. Additional volatile compounds such as more esters and other key aroma volatiles will need to be investigated.

Researchers in the past have attempted to use chemical analysis to predict sensory perceptions in wine. Aznar et al. (2003) examined the prediction of the sensory profile of 57 Spanish red wines from a chemical analysis of the aroma compound groups (e.g. methoxypyrazines). The study selected the highest correlating sensory descriptors and aroma compound groups. These selected correlations were recorded at a range of $r^2 = 0.62 - 0.81$. Commendably, they produced models that explained over 45% of the variance in the data, but the model only incorporated six sensory descriptor groups and unfortunately did not include three highly used sensory descriptor groups, which the panellists felt described the wines evaluated. The authors noted that wine is a complex medium, so that descriptors such as capsicum and green peppers that may not relate to high levels of methoxypyrazines, but perhaps to other aroma compounds, too. Lund et al. (2008) found that high IBMP concentrations did not correlate with high sensory perceptions of the expected capsicum attribute, which also points to the complexity of wine.

In the study of Aznar et al. (2003), there were many negative correlations that would indicate the presence of aroma compounds that had a suppressing effect on the perception of other aroma compounds. This notion of aroma compounds suppressing other aroma compounds could explain the accentuation of 3MH being caused by caffeic acid in this study. Caffeic acid could have bonded with particular aroma compounds that in the presence of 3MH suppress its perception. This current study demonstrated how non-volatile compounds play a role in sensory perception of wine and may explain these negative or low correlations.

Analytical equipment such as GC MS or HPLC can measure the concentration of a non-volatile compound and the concentration of volatiles, but it does not measure the human perception effects of the interaction of non-volatile compounds with volatile compounds. The results of this study support the inclusion of scientific sensory testing with chemical analysis to elucidate the perception of wine aroma profiles. By integrating the two analyses, the more complete results will help to better interpret interactions occurring in the complex wine matrix.

Conclusion

The three polyphenols examined in this research showed varying effects on the key aroma compounds in New Zealand Sauvignon Blanc wine. The differences suggest that currently, each compound needs to be evaluated singularly to fully understand its impact on the whole product or wine matrix. Considering that a wine can consist of 40 or more aroma-active volatile compounds, as well as a range of non-volatiles, this makes for a complex puzzle. Understanding the interaction of non-volatile compounds, such as polyphenols, and their effects on volatile aroma compounds enhances the prediction of flavour profiles through chemical analysis. It also aids winemakers in producing a wine with a desired aroma profile.

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Appendix M: PUBLICATIONS AND CONFERENCES RESULTING FROM THIS THESIS

Publications

Peered reviewed publications

Brajkovich, M.,Tibbits, N., Lund, C.M., Dykes, S., Kilmarten, P., Nicolau, L. (2006). Effects of screwcaps and cork closures on SO_2 levels on Sauvignon blanc wine. *Journal of Food Agriculture* **53** (26): 10006-10011

Lund, C.M., Benkwitz, F., Thompson, M.K., Wohler, M.W., Triggs, C.M., Gardner, R.C. Heymann, H.G., and Nicolau, L. (2009) New Zealand Sauvignon blanc distinct flavour characteristics: sensory, chemical and consumer aspects. *American Journal of Enology and Viticulture*. **60,** 1-12

Lund, C.M., Nicolau, L. Gardner, R.C. and Kilmartin, P.A. (2009) Effect of polyphenols on perception of key aroma compounds of New Zealand Sauvignon blanc wine*. Australian Journal of Grape and Wine Research* **15,** 18-26

Lund, C.M., Jones, V.S. Spantz, S. (2009) Effects and influences of motivation on trained panellists. *Food Quality and Preference*. **20**, 295-301

Non-peered review

Lund, C.M., Thompson, M., Duizer, L, Triggs, C. (2007). New Zealand Sauvignon blanc: What makes it unique and do USA consumers like it? NZ Winegrowers **10**, 43-44,89

Conferences/Workshops

Rathjen-Nowak, C., Lund, C.M. and Jones, V.S. Society of Sensory Professionals Inaugural meeting (2008) Cincinnati, OH, USA. “Intrinsic motivation of trained panels”

Pangborn Symposium (2007) Minneapolis MN USA.

Lund, C.M., Jones, V.S. Duizer, L.M., LaVoi, N. Stapleton, L. and Gilbert, C.Chaired a mini-symposium “Do you know what motivates your trained

panellists?

Lund, C.M. Thompson, M., Duizer, L., Triggs, C.M. and Gardner, R. Poster presentation, New Zealand Sauvignon blanc: What makes it unique and do USA wine consumers"

Lund, C.M. Thompson, M., Duizer, L. and Triggs, C.M. NZ/Australian Sensory and Consumer Science Network Symposium (2007) Whangaporoa NZ "Evaluation of Sauvignon blanc by USA and New Zealand wine consumers"

Lund, C.M. and Thompson, M. NZ Wine Industry Workshop (2006) Auckland and Blenheim, NZ, "New Zealand Sauvignon blanc odours"

Lund, C.M.Yalumba Winery VitiVin conference. (2006) Blenheim NZ "The important characteristics in New Zealand Sauvignon blanc and sensory evaluation in the winery"

Lund, C.M., Thompson, M., Benkwitz, F., Nicolau, L., and Gardner, R. American Society of Enology and Viticulture (2006) Sacramento CA USA "New Zealand Sauvignon blanc: Sensory and chemical analysis of its unique characteristics"

Strada, D. Frost, A. Lund, C.M. Wine Educators' conference (2006) Eugene OR USA "NZ Winegrowers: NZ Sauvignon blanc Presentation and Tasting" from Pernot Ricard

International Cool Climate conference (2006) Christchurch NZ

Lund, C.M., Parr, W. Chaired focus session "Flavours in wine"

Lund, C.M., Thompson, M., Presented focus session, "Deconstructing NZ Sauvignon Blanc".

Pangborn Symposium (2005) Leeds United Kingdom.

Lund, C.M. Oral presentation "Confidence and motivation: How do these factors influence trained panel?"

Lund, C.M., Thompson, M., Sharpe, S., Pripis-Nicolau, L., and Gardener, R. Poster presentation "New Zealand Sauvignon blanc: Sensory and chemical analysis of regional effects"

Romeo Bragato conference (10th-13th annual proceedings for the NZ Winegrowers 2004-07):

Lund, CM (2007) Auckland NZ. Panel discussion "The Wine Consumer"

Lund, C.M., Thompson, M., Triggs, C., Benkwitz, F., Nicolau, L., and Gardener, (2006) Queenstown, NZ "New Zealand Sauvignon blanc: HortResearch Sensory Panel"

Cliff, M. Lund, C.M., and Thompson, M. (2005) Workshop on "Wine flavour description" Gisbourne, NZ

Lund, C.M. (2004) Blenheim, NZ "How much is a wine consumer willing to pay for Sauvignon blanc?"

Lund, C.M. (2005) New Zealand Institute of Food Science & Technology annual meeting "Confidence, confusion and motivation: How do these factors influence trained panel data" Christchurch, NZ