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UNDERSTANDING REGIONAL SENSORY PROFILES OF WHITE WINES IN PENNSYLVANIA

A Thesis in

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by

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ABSTRACT

There has not been much research on the sensory properties of commercial Pennsylvanian (PA) wines, despite the region's history in wine production. Changes to the state's liquor laws in 2016 allow grocery stores and other convenience stores (such as gas stations) to sell wines, necessitating further research in order to set PA wines apart from their regional and international competitors on a grocery shelf. One way to build trust with consumers is establishing regions of origin – sensory profiles unique to specific locales. Regions of origin are beneficial to all producers and brands that fall in the regional designation, and thus could help the PA wine industry both differentiate themselves from competitors and improve the overall recognition of PA wines. Therefore, this thesis explores the viability of sensorially distinct wine regions within Pennsylvania.

The first part of this research explores the sensory distinctness of Pennsylvanian wine regions as they stand, using commercial samples of Riesling and Vidal blanc wines from wineries across the state. Using a trained descriptive analysis panel, differences were found mainly in basic tastes, most likely a result from post-harvest processing (back-sweetening, for example), showing that stylistic winemaker decisions influenced the final state of the wine. The northwest region of the state, by Lake Erie, was characterized by sweeter wines in both Riesling and Vidal blanc varieties, and a more consistent sensory profile. This could be due to the geographical proximity of wineries in this region, which would encourage and necessitate interactions between winemakers and industry professionals. The southeast region was characterized by a semi-distinct profile in their Riesling wines, which were much drier than the northwest, however this was not mirrored in the Vidal blanc wines from this region. Based on these findings, it became apparent that wine professionals should also be tested, to see if these regional sensory profiles (such as those from the northwest) can be identified by the wine professionals themselves, and if they acknowledge these regions when tasting their wines.

Wine professionals from across the state were invited to participate in a free-sorting task of the same Riesling and Vidal blanc wines in order to understand their perceptions regarding similarities and differences without lengthy training. This sorting task found similar results to the descriptive analysis, showing that the wine professionals perceived similar patterns to the trained panel. However, these professionals did not acknowledge the different regions when asked to describe their groupings, meaning more work should follow to understand if wine professionals can group wines based on region if explicitly prompted. The sorting task did enable the south-central region, which was previously not acknowledged by the panel, to be shown as a semi-distinct region mainly trending towards drier wines.

This body of research has found wine regions to be a potential marketing technique for the Pennsylvania wine industry and presents novel research into an emerging fine wine region in the United States.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter 1

Introduction

1.1 Pennsylvania Wine Industry

Pennsylvania (PA) is the sixth largest producer of bulk wine in the nation (Statistical Report - Wine 2017). However, PA is relatively unknown for its wine production among consumers, and PA wines have not been comprehensively researched, both on a fundamental sensory level and in terms of consumer interest and awareness. Instead of relying on a privatized liquor sector, PA wineries mainly rely on cellar door purchases – wines sold directly from the hands of the winery staff to the consumer themselves (Frank 2013). This agritourism effort is partially necessary due to Commonwealth liquor laws and the state-run monopoly stores for wine and liquor ("Fine Wine and Good Spirits" stores run by the Pennsylvania Liquor Control Board, hereby abbreviated to PLCB), but also due to the size of most PA wineries – the majority of wineries classified as small wineries - selling less than 10,000 cases a year (Frank 2013).

Agritourism, and wine tasting specifically, is a common income stream among wineries in the mid-Atlantic region. In a study of over 900 mid-Atlantic consumers (residing in Delaware, New Jersey, or Pennsylvania), 37% responded to previously having participated in wine tastings as part of agritourism (Govindasamy and Kelley 2014). These direct interactions between consumers and producers can often provide more benefits than just purchasing a wine; they also serve as consumer education and increase community ties (Barbieri et al. 2019).

However, the recent change in Pennsylvanian wine laws now allows stores with sit-down cafes to sell to-go wine to their clientele ("Liquor Code - Omnibus Amendment" 2016).Through this act, large grocery stores and gas stations are now selling wine to the Pennsylvanian public, and wine purchasing is thus not limited to winery experiences and specialized PLCB stores. Local wines are now more accessible to the consumer through these regulations, and projections based on an analysis of a similar law proposed in New York found increases in winery revenue by 13% when wine sales would become available through these additional outlets (Rickard 2012). However, local wineries and wine brands now face increased competition from multi-national brands sharing the store shelf. Large wine regions – California, France, Italy, Australia – have a competitive advantage since they are familiar to consumers, so the question becomes how will the small and varied “local wine” section be able to stand out in a retail space? One way to create interest, advance public knowledge of the PA wine industry, and stop inter-regional competition would be to establish distinct wine regions within Pennsylvania that could be used on a wine label to garner more recognition.

1.2 Regional Wine Profiles

Wine regionality is a concept that has been known since ancient times – Roman emperors had wine preferences based on location (for a thorough discussion, see (Thurmond 2016)). Regionality-based marketing is used strategically today in Napa Valley, Chianti, and Bordeaux – special places and wines that convey a specific type and taste to consumers. Many factors can affect the wine experience for a given wine region – governmental regulations, climate, consumer expectations, soil, winemaker preferences, and in some cases, wine critics (McCoy 2005). This terroir, the ineffable quality that makes some growing sites different from others, has been discussed throughout time and often in recent scientific literature (for a nuanced discussion on terroir, see (Ballantyne et al. 2019)).

Researchers have found that wines of the same varietal and year from different locations differ in sensory profile, even when winemaking procedures are controlled. This was found to be the case in a study on Malbec wines from California and Mendoza, where wines separated by country and region of origin when using a descriptive panel (King et al. 2014). In a climate more closely related to Pennsylvania - Ontario, Canada - Riesling wines were found to be different based on ten grape-growing sites within the region of the Niagara Peninsula (Willwerth et al. 2015). However, differences in finished wines are more than the result of the starting grape material, but rather a combination of all practices, including winemaking procedures. Differences have been found many times between wines from different regions without controlling for the influence of winemaking techniques. New Zealand Pinot noir wines have exhibited sensory regionality (Tomasino et al. 2013), and Sauvignon blanc wines have exhibited regional characteristics based on their country of origin in a set including wines from New Zealand, Austria, and France (Green et al. 2011a).

Whatever the cause, wines, along with their winery and wine brand, gain importance as their regional "brand" becomes recognized. In fact, brand and wine region are often closely related, with regions considered to be high quality significantly benefiting the associated brands (Schamel 2006). Region of origin can even override sensory perceptions of quality (tasting) when rated by consumers (Veale and Quester 2009). However, for emerging and unknown wine regions it is still imperative to deliver positive experiences in order to solidify this positive regional brand recognition (García-Gallego et al. 2015). Multiple research studies have found region to be an important feature in gauging the quality of wines and thus consumer choice (Barber and Almanza 2007, Chrea et al. 2011, Sáenz-Navajas et al. 2013).

1.3 Wine Grape Production in Pennsylvania

Vitis vinifera is the most common grape species used in wine production. However, Pennsylvania's long cold winters and wet conditions year-round make growing most common *V. vinifera* varieties difficult. *V. vinifera* clones such as Riesling, Gewürztraminer, and Lemberger (Blāufränkisch) from cooler and wetter regions in Europe (such as Austria and Germany) seem to grow better in the PA climate (for more general PA climate and grape information, see ("PA Grapes Guide" 2020)). However, *V. vinifera* grapes are dwarfed by the number of "native" *Vitis* *labrusca* grapes grown in the state – in the most recent PA orchard and vineyard survey in 2008 – Pennsylvania had over 9,900 acres of this native variety, 657 acres of *V. vinifera*, and 649 acres of interspecific hybrids.

Vitis labrusca, native to the northeastern United States and Pennsylvania, is extremely important to the PA grape growing industry, with well-recognized species like Concord and Niagara being important in juice and jellies. Wines made from this species, however, have a characteristic grapey aroma and flavor often described as "foxy" by those in the wine industry. This sensory characteristic is caused by methyl anthranilate and 2- aminoacetophenone, two odorants absent from *V. vinifera* grapes (Sale and Wilson 1926, Sun et al. 2011). Although some consider these "foxy" characteristics undesirable in wine, wine made from these native grapes is a very important part of the wine industry in Pennsylvania, and wine consumers in PA have a higher tolerance for these flavors than compared to Californian consumers (Perry et al. 2019). While *V. labrusca* grapes are vital to the PA wine industry, the quality of these wines is debated due to their "foxy" characteristics, and thus are not used in this study. For an in-depth understanding of *V. labrusca* grapes and their acceptance in PA, see (Perry 2016).

Inter-specific hybrid grapes are crosses between *V. vinifera* and other grape species, whether *V. labrusca* or others (such as *V. rotundifolia, V. rupestris, V. riparia*). These hybrids contain less "foxy" odors, and are grown mainly in the United States and Canada due to their higher tolerance to disease and harsh climates, as well as in organic wineries where insecticides and fungicides are regulated. Using these grapes can often lead to less pesticide use and better yields for grape growers (Pedneault and Provost 2016).

As *V. vinifera* and hybrid grapes are grown in similar quantities in PA, it warrants researching both grapes when exploring Pennsylvanian wines. Riesling wine and Vidal blanc wine are the two varietals used for analysis. Vidal blanc is a relatively widespread interspecific hybrid variety in Pennsylvania, and has been studied before, albeit usually in an ice wine context (Chisholm et al. 1995). It has not been widely studied in a commercial or consumer context, but has been compared to Riesling wines in terms of aging (again in an ice wine context) (Bowen et al. 2016). *V. vinifera* Riesling wines have been well studied in regard to regionality, and Riesling wines are reported to have characteristic sensory profiles that are consistent from the grapes to the wine, in contrast to other varieties (Winton et al. 1975). Riesling wines have been found to demonstrate regional differences in Ontario (Willwerth et al. 2015), and both regional and winemaking differences in Germany (Fischer et al. 1999). Both varieties were also chosen based on their relative availability in Pennsylvania through experience and recommendations from industry professionals.

1.4 Wine Consumers

Consumers are increasingly interested in how their food is being grown, and this phenomenon has extended to the wine industry. Organic and Biodynamic wine have gained significant traction in the industry, with a recent comprehensive study of Gault Millau, a German wine publication, finding 23% of wineries featured from 2010-2017 enacting organic or biodynamic processes (Fanasch and Frick 2020). Sustainable practices are becoming more important to Pennsylvanian consumers as well. In the mid-Atlantic region, Kelley found that when consumers were informed about sustainable wines, they would be more willing to purchase a bottle of sustainably produced wine with a $1 price premium at $12 and $16 price points, though this affect was not seen at the higher price points of $22 and $26 (Kelley et al. 2017).

With this interest in sustainable practices, a market opportunity may exist for wines made from grapes that are more resistant to pest and disease pressure, such as hybrid and native varieties (Pedneault and Provost 2016). A recent study by Perry found that Pennsylvanian consumers are not adverse to methyl anthranilate and 2-aminoacetophenone in wines when analyzed by rejection thresholds, in contrast to those in other areas less familiar with the flavor, such as northern California (Perry et al. 2019). Therefore, mid-Atlantic consumers may find these hybrid wines to be acceptable based on flavor the potential for sustainable production, including a reduction in pesticide applications, if informed about these and other environmentally-friendly practices. However, these hybrid varieties are often not familiar to consumers.

Wine, unlike other consumer goods, is purchased at a store almost solely based on its extrinsic properties. In a common store, there is no way to look, taste, or know what you will get in a bottle of wine until after you open it. This causes consumers to make decisions solely based on the wine bottle and previous experience. Wine selection is then a risk-reducing strategy – enacting memory and packaging cues to choose the wine that will be least likely to disappoint. See (Barber and Almanza 2007) for a discussion on the complexities of wine purchasing, and the importance of wine packaging for a Connecticut wine consumers survey.

In this risk-reducing purchasing state, consumers use label cues as a way to predict quality. (Sáenz-Navajas et al. 2013) explored the way that wine quality is judged based solely on labels in a French population, finding label style and region of origin to be important for consumer perception. In (Chrea et al. 2011), wine consumers again used packaging to make their quality decisions, however, the results were also strongly modulated by price, with higher prices indicating higher qualities. In a study involving Australian consumers, it was found that they relied more on this extrinsic information than their own sensory wine judgement when judging wine quality (Veale and Quester 2009). When focused on sustainable wine production, (Troiano et al. 2016) found that local claims on a label affected the purchase intent of consumers more than organic production claims in Italy. These findings indicate a region or country of origin claim is a quality factor that is trusted by consumers, sometimes more than their own sensory experiences.

While Pennsylvania has five American Viticultural Area (AVA) designations, no official research has investigated the sensorial differences between wines made in the different regions of the state. Understanding the regional profile as it currently exists can aid the industry in understanding how it can improve and promote trust in its brand. While agritourism and educating the public are important parts of this process, evaluating regionality could help to both unify Pennsylvanian producers and find quality factors to promote. Analyzing wine regions through sensory science has been done many times in recent years, with trained panelists, wine experts, and with general consumers.

1.5 Descriptive Analysis

Of the techniques used for sensory profiling, general descriptive analysis (DA) has been the golden standard. This process entails training a small group of panelists to identify attributes that are present and important to a product, and then having them rate those attributes quantitatively (Lawless and Heymann 2010). Panelists usually taste and discuss the full set of samples over training sessions to find the important and measurable sensory characteristics of the full range of products. They work towards a common vocabulary and experience through references provided by a panel leader based on previous discussion, until a solidified sensory framework on which to evaluate the samples is created. Lastly, the panelists individually rate the test samples using the consensus vocabulary, evaluating the differences in the product. The resulting information gained about the products can be extremely detailed, and often serves as a starting point for future research. This technique has been used extensively for sensory profiling in wines (e.g. (McMahon et al. 2017, Piombino et al. 2004, Williamson et al. 2018)), and has been used specifically for sensory regionality in wines as well (Fischer et al. 1999, King et al. 2014, Willwerth et al. 2015). Therefore, this method was selected for exploring the regionality of PA white wines and to differentiate their sensory profiles in this work. However, there are some detriments to this method, mainly the cost involved in training the panel, and the time it takes to train and maintain the panel. Therefore, other quicker methods have been used to gain similar profile results in recent years.

1.6 Free Sorting

One of these quicker sensory profiling methods is free sorting. Free sorting involves grouping objects together based on similarity (Chollet et al. 2014, Courcoux et al. 2015). In contrast to descriptive analysis, participants do not need to be extensively trained, and usually only require a brief description of the task itself. Therefore, this method allows for a more diverse group of participants: this process has been used with both wine experts and novice wine consumers to better understand how each group conceptualizes wines (Ballester et al. 2008, Schlich et al. 2015). This method also benefits by being a rapid process. Those who may not have the time to conduct a descriptive analysis (such as wine professionals holding demanding jobs) are able to conduct a free sorting task. Adding a verbal or written description of a group can further the information gained and can help understand the separation between samples. In (Lahne et al. 2018), Amari liquor professionals used words to describe their groups, which then were used to find differences in sensory profiles. This technique allows experts to use their specific lexicon, which is different from that of a trained panel or consumers. For these reasons, free sorting was used in this research to understand the PA industry’s wine professionals and if they were able to separate wines by region or regional sensory profile.

1.7 Wine Experts

Much work has involved looking at the differences between wine professionals and consumers. It has been found that training in sensory aspects of wine can lower one’s perceptual thresholds for wine-specific compounds, and that those who are experts in the wine field have lower thresholds than those without that expertise (Tempere et al. 2011, 2016). Wine experts, as mentioned above, also use different vocabularies than consumers, and even than experts in other products, as (Croijmans and Majid 2016) found by comparing wine experts to untrained panelists and coffee experts. However, wine professionals have been found to create similar perceptual profiles to that of trained panels (Hopfer and Heymann 2014). As professionals whose daily jobs directly affect the wine region of which they are a part, it is important to also understand the role and sensory observations of Pennsylvanian wine professionals.

1.8 Conjoint Analysis

Conjoint analysis has been used many times to understand the choice behavior of consumers, as this technique gives more ecological validity to questionnaires. Originally done on paper “cards”, this method includes presenting consumers with a few different options that vary in certain factors of interest and having them select their most preferred option. In this way, researchers are able to pull apart the driving interest of participants in a relatively short amount of time. While older versions of this analysis were done by hand, and could take hours, the internet and advanced computers able to run algorithms quickly have made this technique much more viable and take the individual participants only minutes to complete.

With this advancing technology, different types of conjoint analyses have been developed, however choice-based conjoint analysis as described above is extremely popular, as it simulates what a consumer would do in a marketplace. A more complete summary can be found in (Moskowitz and Moskowitz 2012). This technique has been used in the wine industry many times to understand the interactions of label information and consumer choice (Kelley et al. 2017, Lockshin et al. 2006, Veale and Quester 2009).

1.9 Summary

To summarize, the Pennsylvanian wine industry is changing, and is looking for ways to promote PA wines, which are currently made from native, hybrid, and European grape varieties. One potential way to promote PA wines this is through understanding the differences between wines from grapes grown in separate regions of PA. Sensory profiling of wines through descriptive analysis can aid in discovering and defining regional profiles. Free sorting is a way to do this more quickly with wine professionals, who define the taste of wine in their regions, and who can give more information on the Pennsylvania wine industry. Communicating these regions would then fall to the extrinsic factors surrounding the wine, primarily the wine label, which has often been studied using conjoint analysis. Wine regions have been shown to promote trust, like brands, to wine consumers. Therefore, this thesis addresses the following hypothesis.

1. I hypothesize that wine regions exist in Pennsylvania and will be found through descriptive analysis using trained panelists and free sorting using wine professionals from Pennsylvania.

Chapter 2

Exploring Sensory Regionality of Commercial Pennsylvanian White Riesling and Vidal Blanc Wines

2.1 Introduction

Wine has been categorized by the location of origin for centuries and such labelling has become a distinct feature on wine packaging across the world. Location is important as it often indicates a distinctive wine style to consumers, who in many cases base their purchasing decisions on past experiences with wines from a certain region. Wine region has been shown to be a factor that consumers consider strongly when deciding to buy a wine (Thach 2008): The origin or appellation of a wine was ranked 4th after prior tasting experiences, recommendations by a friend or sales person, and varietal.

These region of origin differences can both be attributed to terroir, the idea that land, soil, and climate impart sensory differences, as well as winemaking style. These are often defined and regulated in 'Old World' wine regions, where regional typicality of wines is an important quality concept.

Research has found distinct regional wine profiles in both white and red *Vitis vinifera* varieties (Green et al. 2011b, King et al. 2014, Tomasino et al. 2013). For red Pinot noir wines from New Zealand (regions of Central Otago, Marlborough, Martinborough, and Waipara) Tomasino and coworkers (2013) found that wine experts were able to separate finished commercial wines by region.

Similarly, King et al. (2014) found distinct sensory fingerprints between California and Mendoza as well as sub-regions within these two regions for Malbec wines through descriptive sensory analysis (DA), though the studied wines were not available commercially and winemaking was controlled. Winemakers from Marlborough, New Zealand, found regional sensory differences in blind tastings for white Sauvignon blanc wines from Austria, France, and New Zealand and were able to group the wines by country (Green et al. 2011b).

Within- country differences on a local level have also been researched for region-specific profiles. In a study on Rieslings from sub-regions within the Niagara Peninsula in Ontario, Canada, sensory sub-regionality, or distinct sub-regional fingerprints were found both chemically and by descriptive analysis (DA) when the winemaking process was controlled. Observed differences were mainly attributed to the varied climates and their effect on grape composition between the different sub-regions (Willwerth et al. 2015). In commercial Riesling wines from Germany, Fischer and coworkers (1999) found that while certain regions showed site-specific sensory fingerprints (e.g., Rudersheimer Berg Scholbberg), the effect of vintage and winery/winemaking overwrote potential site-specific profiles for other regions (e.g., Erbacher Marcobrunn). The authors concluded that location designations alone would be more confusing to consumers, as vineyard location was only one important factor defining the sensory profile of the resultant wines.

In summary, prior studies have reported sensory regionality in both red and white V. vinifera wines, however, they also found that winemaking has a strong impact on final wine sensory properties and may affect site-specific differences.

Pennsylvania (PA) is one state where wine sensory regionality could play a role in promoting and diversifying state production. As of 2017, PA had over 13,500 acres of land dedicated to grape-growing (2017 Census of Agriculture - State Data, Pennsylvania: Table 37. Specified Fruits and Nuts by Acres: 2017 and 2012 2017), though most of these acres are dedicated to juice and table grape production. The most recent PA orchard and vineyard survey in 2008 found 657 acres of *V. vinifera*, 649 acres of hybrid, and over 9,900 acres of native grapes grown in the state. The PA wine industry ranks sixth of the 50 US states in bulk wine production and fourth in bottled wine production (Statistical Report - Wine 2017), and the wine industry in PA is developing into a solidified professional industry.

Although PA has five American Viticultural Areas (AVAs), it lacks scientific data relating wine sensory properties to the various growing regions throughout the state. Given the variety of climates, geology, and topography throughout PA - encompassing climate effects from Lake Erie, the Appalachian Mountains, and multiple river valleys - one could justifiably expect distinct sensory regionality among Pennsylvanian wines in both terroir and winemaking style. Such regional profiles would allow local winemakers to promote their wines and differentiate Pennsylvania in the broader regional market as a state with diverse wine profiles.

Both varietal and regional typicality are considered important aspects of wine (Charters and Pettigrew 2007). Riesling grapes are reported to have a very “typical” or grape variety-driven sensory profile (Winton et al. 1975), and the grape has been used previously in regional studies with similar climates (Fischer et al. 1999, Willwerth et al. 2015). This history of typicity in other regions and countries makes Riesling a useful variety to study wine regionality in Pennsylvania as it is grown throughout the state.

In contrast to ‘Old World’ wine regions and even more established ‘New World’ locations such as California and Australia, Pennsylvania’s wine industry is also characterized by a significant hybrid grape and wine production, mainly to manage disease pressure during the wetter growing season and cold winters. One of the more commonly grown interspecific hybrids is Vidal blanc, which is also used in similar wine styles as Riesling. Vidal blanc wines have been studied using sensory science in ice wine production (Bowen et al. 2016, Nurgel et al. 2004) as well as aging potential (Chisholm et al. 1995). However, sensory comparisons of regional Vidal blanc table wines have not been studied to date.

This study evaluates anecdotal evidence of sensory wine regionality in wines from Pennsylvania. Specifically, this research aims to see if sensory differences exist between commercial white wines grown in different PA regions, and if wines from these regions form distinct sensory profiles. We hypothesize that Riesling and Vidal blanc wines from Pennsylvania can be separated into geographical region by their sensory profiles, as assessed by a trained DA panel. We expect that these differences will be remain stable over year and varietal.

2.2 Materials and Methods

All research protocols were evaluated by The Pennsylvania State University Institutional Review Board (protocol #STUDY00008551) and found to be exempt under category 6 (Taste and Food Quality Evaluation).

2.2.1 Samples

A total of 70 (61 Pennsylvanian) wines were studied over a period of two years. In year one, 27 white wines (15 Riesling, 12 Vidal blanc) were collected through purchase or donation (12x750 mL bottles each), with 13 Riesling and 10 Vidal blanc wines from Pennsylvania, and two of each varietal from outside the Commonwealth. For the second year of study, more wineries were included, totaling to 43 (22 Riesling, 21 Vidal blanc) wines, with five wines outside Pennsylvania (2 Riesling, 3 Vidal blanc). All Pennsylvanian wines were made of grapes grown entirely in Pennsylvania and were at least 75% of the chosen varietal (Riesling or Vidal blanc). It should be noted that one winery used as a Pennsylvanian wine in this study was actually produced in Erie, New York, less than 10 miles from the PA border. This sample was labelled a “northwest PA” wine, as it was produced so close to the other wines in the series, and is an influential part of the Lake Erie community.

Wines were grouped into regions based on the location of the vineyards when available; if no vineyard information was given, the location of the winery was used. Wines spanned from the

2015 to 2017 vintages between the two years of collection. Wineries from the first year of assessment were also included in the second DA with the exception of two, which did not produce the consecutive vintage. Wines were stored in their original bottles and packaging at room temperature until sampled (within 6 months of purchasing). Appendix Tables 1 A and B list the wine vintage, region, retail price, if known, and closure type.

Basic wine chemistry analyses were conducted by the Cornell Geneva New York State Wine Analytical Laboratory (Geneva, New York); this included pH, titratable acidity (TA), fermentable sugar (RS), ethanol content (EtOH), malic acid content (MA), volatile acidity (VA), and free (FSO2) and total sulfur dioxide (TSO2) concentrations.

2.2.2 Descriptive Sensory Analysis

For the first year, a descriptive analysis (DA) panel of eight people (seven females and one male, 24-63 years old, recruited from the State College, PA area) was trained for nine hours on attributes found in the wines. The panel developed a list of 14 aroma, 13 flavor, three taste, and two mouthfeel attributes (Table 2.1). For the second year, a DA panel of 12 people (nine females, 23-60 years old) was trained for 12 hours on the attributes created from the previous year, with the option to add attributes. In both instances, panelists were selected from the Sensory Evaluation Center database at The Pennsylvania State University (University Park, PA) based on prior experience, willingness and interest to evaluate wine, and being over 21 years of age. While effort was made to retain the panelists for both years, only four of the eight original panelists were able to repeat the study in the second year.

Panelists in both years were first trained on basic tastes and mouthfeels with aqueous solutions of representative compounds (Table 2.1). Blindly evaluating wine samples, the panelists developed aroma and flavor attributes over multiple training sessions, accompanied by iterations of references until the panel agreed on references for the descriptors (Table 2.1).

Panelists were then trained to use the references consistently and underwent training on scaling. In year one, all 27 wines were presented at least once during training. Blind duplicate testing was done to confirm panel consistency, indicating readiness for testing. For the second year, the finalized list from the first year was used, and panelists were trained with the same references, with the option to add references if they felt it was needed. In the second year, the panel chose to add sulfur, brothy, bready/yeasty, and anise aroma and flavor attributes, along with a viscous mouthfeel attribute to the ballot. The second-year panel also chose to add an ethanol flavor attribute, while this was only included as an aroma reference in the first year. Panelists in the second year did not see all 43 wines during training; however, wines used in training were pre-screened by the researchers, selecting wines with characteristics not found in the original list of attributes. Again, blind duplicate wines were used to analyze panelist performance and readiness for testing. In both years, an “Other” comment box was provided for scaling of any other aromas, flavors, or mouthfeels.

2.2.3 Sample Evaluation

In year one, wines were evaluated on nine separate tasting days, with six samples tasted per session. Wines served in a session were from the same grape variety. For the second year, to accommodate the number of samples, panelists had 12 days of testing, with ten to 12 samples tasted per session (two sets with five to six samples per set). A ten-minute break was enforced halfway through each session, where panelists were encouraged to stand up and walk around outside the testing area. Tasting sessions were at least one day apart.

Two ounces of each wine sample were served in covered, clear ISO certified tasting glasses, labeled with three-digit blinding codes, and served at room temperature. Pitchers of DI water and unsalted crackers (Premium unsalted tops Saltine Crackers, Mondelez Global LLC, East Hanover NJ) were supplied for palate cleansing, with more crackers available upon request.

All wines were tasted in triplicate in individual tasting booths under white light, using a modified counterbalanced design, with data collected in Compusense Cloud, Academic Consortium (Guelph, Ontario, Canada). Panelists were instructed to smell the wines to evaluate all aromas, then to taste and expectorate to evaluate taste and flavor attributes. Appearance, while discussed in the training sessions, was not deemed important or different enough in both years by the panel and was thus not rated. Panelists were compensated for their time according to the approved IRB rate ($10/hr.).

2.2.4 Data Analysis

DA results were extracted from Compusense and analyzed in R Studio (version 3.4.3, Boston, MA, USA). The SensMixed package (Kuznetsova et al. 2018) was used to run a mixed-effects analysis of variance (ANOVA) on each data set, separated by grape variety and DA panel. Missing data (e.g., a panelist missing a single session) was computed using panelist replicate means. Using the SensoMineR package (Le and Husson 2008), principal component analyses (PCA), along with bootstrapping confidence intervals were created. Partial Least Squares Regression (PLSR) modelling of basic chemistry and sensory data was done with the pls package (Mevik and Wehrens 2009).

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Table 2.1. *Descriptors and corresponding references used by the Descriptive Analysis (DA) panels in both years*

Descriptor	**Reference** [a]
Citrus	3 x 2 cm fresh lemon peel (Wegmans, State College, PA) in 20 mL wine
Stonefruit	11.5 g fresh yellow peach + 24 g canned apricot + 4 tsp canned apricot juice in 40 mL wine (fresh fruit from Wegmans; Wegmans halved unpeeled in pear juice from concentrate, Rochester N)
Pear	43.5 g fresh green pear (Wegmans) in 20 mL wine
Green Apple	10.0 g fresh Granny Smith apple (Wegmans) in 20 mL wine
Mixed Fruit	3 pineapple chunks + 3 grapes + 3 peach chunks + 2 cherries + 9 tsp juice + 1 strawberry (Wegmans fruit cocktail in pear juice from concentrate, Rochester NY; Wegmans frozen mixed berry fruit, Rochester NY) in 40 mL wine
Canned Veg	1/2 tsp canned pea juice + 1/2 tsp canned green bean juice (Wegmans canned small sweet peas; Wegmans canned cut green beans, Rochester NY)
Soil/Mushroom	1 tsp soil (Indoor Potting Mix, Miracle Gro Lawn Products Inc., Marysville OH) + 2.6 g soaked mushroom + 5 drops mushroom-wine (2.6 g mushrooms in 20 mL wine) (Wegmans petite baby Bella mushrooms, Rochester NY)
Wood	11.1 g wood chips (Kingsford Alder smoking chips, distributed by Barbeque Wood Flavors, Ennis TX) + 5 drops water
Chemical	0.5 mL ethyl acetate (VWR, Radnor PA) in 40 mL wine
Honey	2.7 g clover honey (Wegmans Clover Honey, Rochester NY) in 20 mL wine
Floral	1 mL of 1 jasmine pearl soaked overnight in 20 mL wine + 3 mL solution of 20 drops of geranium stock solution (1 drop essential oil in 100 mL wine) in 20 mL wine + 1 mL of 25 drop rose stock solution (2 drops of rose essential oil in 25 mL wine) in 20 mL wine (Rishi Jasmine pearl loose leaf green tea, Milwaukee WI; Aura Cacia organic pure essential geranium oil; Aura Cacia rose otto in jojoba oil, Norway IA)
Ethanol	2 mL of 95% Ethanol (Kopec 190, King of Prussia PA) in 20 mL wine
Oxidized	3 golden raisins + 8 mL dry Sherry in 40 mL (Wegmans golden raisins, Rochester NY; Taylor Wine Dry Sherry, Pulteney NY)
Grape	8 mL white grape juice + 3 halved fresh green grapes + 8 mL decarbonized sparkling white grape juice + 4 mL concord grape juice (Wegmans White Grape juice organic from concentrate, Rochester NY; Wegmans, State College PA; Kedem Sparkling Catawba Grape Juice, Kedem Food Products, Marlboro NY; 100% Organic Grape Juice, Apple and Eve LLC, Roslyn NY)
Anise[b]	20 anise seeds in 20 mL wine (McCormick & Co Inc, gourmet organic anise seed, Hunt Valley MD)
Brothy[b]	1 pinch instant beef bouillon in 40 mL wine (Herbox beef flavor instant bouillon and seasoning with other natural flavors; Hormel Foods Sales LLC, Austin MN)
Bready/Yeasty[b]	1 pinch Baker's yeast + 3 drops of water (Fleischman's ActiveDry Yeast, ACH Food Companies, Memphis TN)
Sulfur[b]	Matchbox strip (Diamond greenlight strike matches, Hearthmark LLC, Daleville IN)
Sweet Taste	10 g/L sucrose in water (Pure Cane Granulated Sugar, Domino Foods Inc., Yonkers NY)
Sour Taste	1.5 g/L tartaric acid (Sigma-Aldrich, St. Louis MO)
Bitter Taste	0.8 g/L caffeine (Sigma-Aldrich)
Astringent MF	1.5 g/L alum (McCormick)
Warm/hot MF	6% solution (v/v) ethanol (Kopec)
Viscous MF[b]	1.5 g/L Carboxyl Methylcellulose (TIC gums, Belcamp MD)

[a] All standards were created using Bota Box® Pinot Grigio (Bota Box Vineyards, Manteca, CA) boxed wine, unless otherwise noted.
[b] These attributes were only used in the second sensory descriptive analysis.

Growing degree days (GDD) were calculated as days with average temperatures over 50° F for the closest weather stations to the vineyard locations from the Network for Environment and Weather Applications database accessed online through Cornell University (newa.cornell.edu). Region classification for each wine was based on county lines as used by the PA Winery Association (PWA), the non-profit trade organization of the Commonwealth (see (“PA Grapes Guide” 2020)). The state was thus divided into six regions, namely, the northwest (NW), north central (NC), northeast (NE), southeast (SE), south central (SC), and southwest (SW) areas (Figure 2.1). The southwest part of Pennsylvania (SW) has a lower level of grape production than other regions in the state, thus, the only wines from that region that qualified for this research were Vidal blanc wines analyzed in the second year.

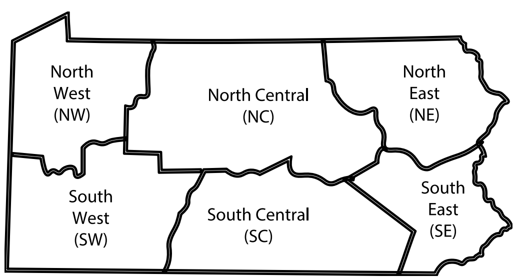

Figure 2.1 *Geographic wine regions in Pennsylvania as noted by the PA Winery Association (PWA; pennsylvaniawine.com), which separates regions along county lines. The same regional classification was used in this study.*

2.3 Results

2.3.1 Commercial Riesling and Vidal blanc wines from Pennsylvania show significant differences between wines and regions

The first year DA panel found the 15 Riesling wines to differ significantly ($p < 0.05$) in 10 of the 14 aroma, six of the 13 flavor, and all five taste and mouthfeel attributes. Similarly, for the Vidal blanc wines, six aroma attributes, eight flavor, and all five taste and mouthfeel attributes were significantly different between the 12 wines ($p < 0.05$). The second year DA panel found that the 22 Riesling wines differed significantly ($p < 0.05$) in 14 out of the 18 aroma, 16 of the 18 flavor, and all six taste and mouthfeel attributes, while for the Vidal blanc wines 13 aroma, 17 flavor, and all six taste and mouthfeel attributes differed significantly between the 21 wines ($p < 0.05$). A summary of the significantly different attributes for each wine and each evaluation year, together with the Least Squared Means (LS Means) post-hoc comparison results is provided in Appendix Tables 2 A-D.

In order to further explore whether these sensory profile differences could be the result of sensory regionality, an analysis of variance (ANOVA) for the region factor was conducted.

For the Riesling wines in year one, three aromas, four flavors, and four taste and mouthfeels showed significant regional differences ($p < 0.05$), while in year two, two aroma, six flavor, and three taste and mouthfeel attributes differed significantly between the regions (Table 2.2). For Vidal blanc wines, year one panelists only found one flavor and three taste attributes to differ between regions, while in year two, two aroma, five flavor, and three taste attributes were significantly different between regions (Table 2.3).

Sweet taste, sour taste, and bitter taste were consistently different between regions for every varietal and year of analysis, with SE Rieslings being in the highest bitter and sour taste in each year, and the NW Vidal blanc wines being highest in sweet taste in both years. Aroma and flavor attributes were not consistent in their differences within variety, however some of these were consistent within year, with soil/mushroom and canned vegetable aroma and honey, grape, mixed fruit, and canned vegetable flavors being significant in both varieties from the second year of DA.

Table 2.2 *Table of the significant differences between Pennsylvania regions for Riesling wines. Values that share the same letter designation within column and year are not significantly different according to Tukey's post-hoc comparison (p < 0.05).*

	Aromas					**Taste & Mouthfeel**			
	Apple	**Grape**	**SoilMush**	**Chem**	**CanVeg**	**Sweet**	**Sour**	**Bitter**	**Astringent**
Year 1									
NC	--	1.53 ab	--	1.63 ab	1.04 b	1.83 a	3.11 ab	1.740 ab	3.27 ab
NE	--	1.51 ab	--	1.27 ab	0.61 ab	3.29 bc	2.69 a	1.242 a	2.68 ab
NW	--	1.96 b	--	1.15 a	0.44 a	3.58 c	2.25 a	0.925 a	2.53 a
SC	--	1.56 ab	--	0.97 a	0.69 ab	2.71 ab	3.04 ab	1.592 ab	3.46 b
SE	--	1.39 a	--	2.00 b	0.60 ab	2.10 a	3.66 b	2.080 b	2.67 ab
Year 2									
NC	2.16 b	--	1.50 ab	--	--	6.35 c	3.08 a	1.57 a	--
NE	1.26 ab	--	1.89 ab	--	--	5.88 c	4.12 ab	1.85 ab	--
NW	1.63 ab	--	1.59 a	--	--	3.89 b	4.58 b	2.62 b	--
SC	1.33 a	--	2.34 ab	--	--	3.27 ab	5.00 b	3.04 bc	--
SE	1.53 ab	--	2.20 b	--	--	2.89 a	5.20 b	3.30 c	--

	Flavors (in-mouth Aromas)							
	Citrus	**Chem**	**CanVeg**	**SoilMush**	**Pear**	**MxFrt**	**Honey**	**Grape**
Year 1								
NC	1.16 ab	1.88 ab	0.50 b	0.24 ab	--	--	--	--
NE	1.27 ab	1.15 ab	0.19 ab	0.14 ab	--	--	--	--
NW	1.14 a	0.96 a	0.13 a	0.14 a	--	--	--	--
SC	1.12 ab	1.23 ab	0.25 ab	0.38 b	--	--	--	--
SE	1.73 b	1.58 b	0.28 ab	0.134 ab	--	--	--	--
Year 2								
NC	1.80 a	--	1.07 ab	--	2.20 b	2.22 b	3.07 c	2.51 b
NE	2.28 ab	--	0.67 a	--	2.21 ab	1.63 ab	2.78 bc	2.33 ab
NW	2.57 ab	--	1.16 a	--	1.86 ab	1.36 a	1.65 a	1.66 a
SC	2.55 ab	--	1.37 ab	--	1.57 ab	1.11 a	1.39 a	1.51 a
SE	3.06 b	--	1.70 b	--	1.44 a	0.99 a	1.33 a	1.51 a

SoilMush = Soil/Mushroom, CanVeg = Canned Vegetable, MxFrt = Mixed Fruit

Table 2.3 *Table of the significant differences between Pennsylvania regions for Vidal blanc wines. Values that share the same letter designation within column and year are not significantly different according to Tukey's post-hoc comparison (p < 0.05).*

	Aromas		**Taste**		
	CanVeg	**SoilMush**	**Sweet**	**Sour**	**Bitter**
Year 1					
NW	--	--	4.24 c	1.99 a	1.13 a
SC	--	--	2.28 a	3.39 b	2.14 b
SE	--	--	3.50 b	2.54 a	1.43 a
Year 2					
NW	1.66 a	1.46 a	6.12 c	3.45 a	1.94 a
SC	1.87 ab	1.66 a	3.38 a	4.70 bc	3.15 b
SE	1.70 a	1.37 a	4.48 b	4.26 b	2.61 ab
SW	2.69 b	2.53 b	3.05 a	5.26 c	3.48 b

	Flavors (in-mouth aromas)					
	Citrus	**MixFrt**	**CanVeg**	**Honey**	**Floral**	**Grape**
Year 1						
NW	0.68 a	--		--	--	
SC	1.24 b	--		--	--	
SE	0.83 ab	--		--	--	
Year 2						
NW	--	2.12 b	0.77 a	2.82 c	1.68 ab	2.71 b
SC	--	1.33 a	1.08 a	1.65 ab	1.55 a	1.62 a
SE	--	1.92 b	0.92 a	2.15 b	2.11 b	1.89 a
SW	--	0.87 a	1.80 b	1.18 a	2.09 ab	1.57 a

SoilMush = Soil/Mushroom, CanVeg = Canned Vegetable, MxFrt = Mixed Fruit

Subsequent Principal Component Analysis (PCA) was used to visually explore the potential sensory regionality of commercial Pennsylvanian white wines (Figure 2.2).

In both years and for both varietals, over 51% of the total variance was captured within the first two dimensions. While a drop in eigenvalues was observed after two dimensions for the first year of Vidal blanc wines, all other data sets (two years of Riesling and year two of Vidal blanc) showed a drop in eigenvalues after three dimensions. However, in each year, the interpretation of the results did not change when considering the third dimension, nor did any new separation occur, so two dimensions were kept for all four PCA biplots (Figure 2.2).

Looking at the PCAs together with the results of the ANOVA by region, a few key regional differences become apparent. First, in all but the second year's Riesling wines, wines from the northwest (NW) region were characterized by the highest ratings in the sweet taste attribute, leading to sample separation by sweetness ratings along PC 1. Additionally, corresponding aroma and flavor attributes were also found to be highest in the NW region and significantly different from the other regions. For example, grape flavor in the Rieslings assessed in the first year and the second year Vidal blanc wines as well as honey flavor in the second year Vidal blanc wines were rated significantly higher in the wines from the NW region (Tables 2.2-3).

Conversely, wines from the southeast (SE) region were characterized by higher sour and bitter taste ratings in both years for the Riesling wines. Additionally, citrus and chemical flavor in the first year of Riesling wines were also highest in the ones from the SE region, which may be explained by cross-modal associations with sourness and bitterness. These wines were significantly less sweet than the NW in both varieties in both years, showing some consistent regional differences (Tables 2.2-3).

For the bitter and sour taste attributes, Vidal blanc wines from the SE did not show the same trend as the Riesling wines from the SE, most likely indicating a varietal effect for these taste attributes.

The south-central (SC) region was the only other region that was replicated in both years and varieties. Vidal blanc wines from this region were found to be the sourest and least sweet; however, no other sensory attributes were found to be consistently higher or lower, leading to less defined regional sensory profiles (Tables 2.2-3).

Looking at the PCA biplots (Figure 2.2) in addition to the trends observed by ANOVA, further insight into regional groupings emerged. Certain regions (e.g., SC and NE), while showing overlapping 95% confidence ellipses with other regions, still grouped together with few outliers. For example, the SC region in both the first year Vidal blanc and second year Riesling maps generally grouped together. This shows that despite the confidence ellipses around the different regions overlapping, thus, regions were not statistically different from each other, there is potential for a regional sensory profile if more datapoints could be added.

While the PCA allows for an easier categorization of regions by their sensory profiles, it also helps to identify outliers within a region: In year one, two of the Vidal blanc wines from the SE region were located in quadrants two and three, quite separate from the otherwise closely-grouped set of SE Vidal blanc wines. While these particular two wines were closely associated with sour taste, citrus flavor and chemical flavor, all other wines in the SE group showed more similarity to wines from the NW region. Similarly, for year two of the Vidal blanc data set, where one wine from that region is located further away from the other SE Vidal blanc wines, thus showing a quite different sensory profile.

As mentioned above, the SC region showed some overlap and general grouping in the PCA plots, lending to the idea that with more data points a more defined regional profile could be uncovered. Similarly, with the few NE wines tested, the Rieslings stayed in the same general area of the PCA each year. The NC Riesling wines showed great variation between years, so no general conclusions could be made, and more wines are needed to better explore this region. Similarly, the SW region was too variable in the one year and variety in which it was present.

In general, the nine non-Pennsylvanian wines trended towards the origin of each plot, especially in each of the Vidal blanc years (with the exception of one notable outlier in the 2018 Vidal blanc data). The results were mixed in the Rieslings: in the first year the non-PA regions trended towards the NW region, and in the second year they separated out, with one wine trending towards the SE and the other out on its own in the third quadrant. Apart from the 2018 Vidal blanc outlier, each non-Pennsylvanian wine was within the spectrum of PA wines, showing that overall, Pennsylvanian wines are able to express similar sensory profiles as wines from outside PA, such as New York, Washington state, and Virginia.

Lastly, on each PCA the supplementary variable of growing degree days (GDD) was included. This data was used as a measurement of how climate could play a role in the sensory profile. Based on the PCA plots (Figure 2.2), it seems that GDDs are negatively associated to fruity aromas and flavors such as mixed fruit, stone fruit, and grape. The GDDs also trended away from NW wines and towards southern wines (SE and SC), showing that the NW receives less GDDs per harvest than the SE and SC regions.

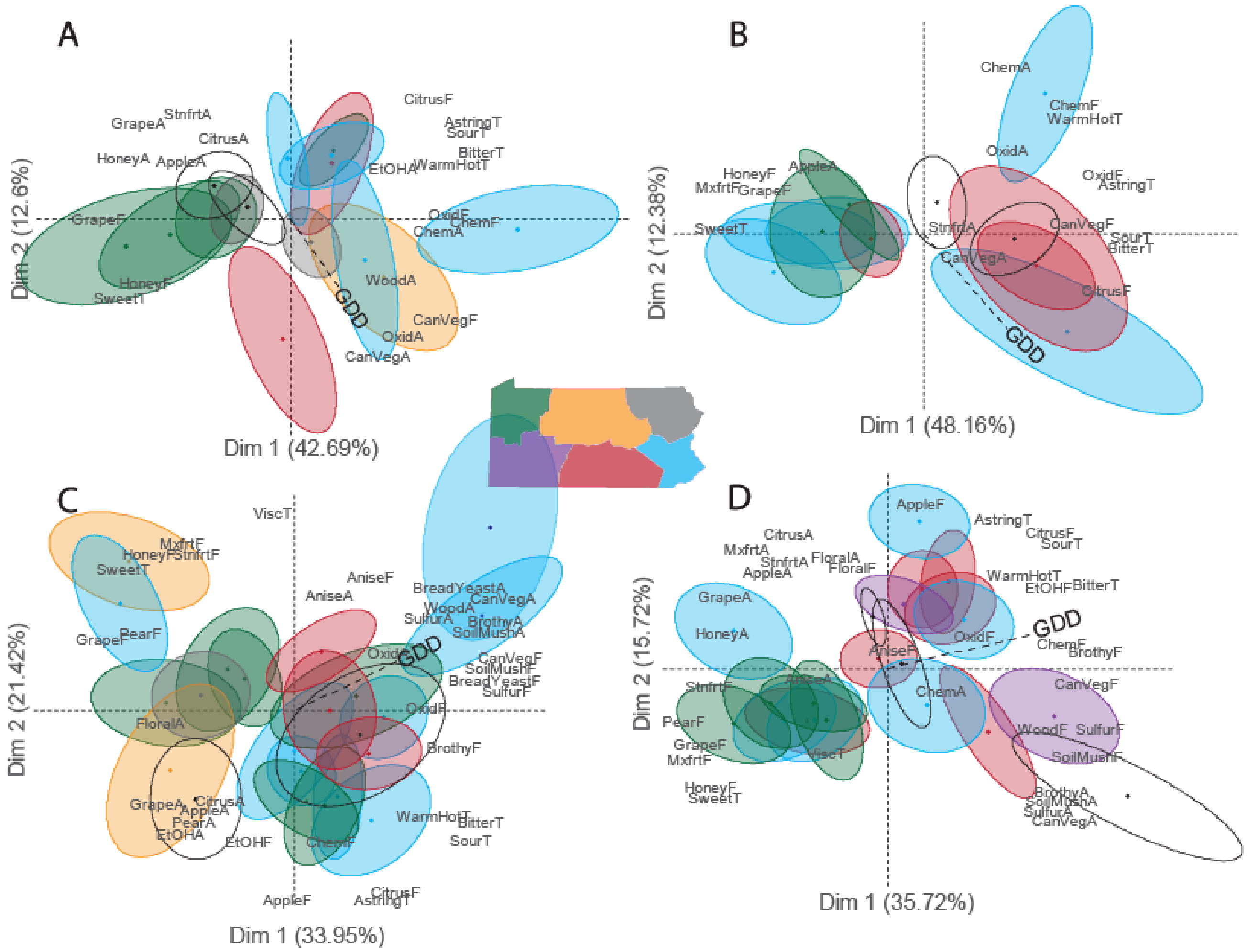

Figure 2.2 *PCA biplots showing the significantly different sensory attributes (p < 0.05), evaluated by DA, for A) Riesling wines assessed in the first year B) Vidal blanc wines assessed in the first year, C) Riesling wines assessed in the second year, and D) Vidal blanc wines assessed in the second year. Wines are shown with their 95% confidence ellipses and coded by region with different symbols. Overlaid are sensory attributes, as well as growing degree days (GDD). Attributes ending in A indicate aroma, F indicate flavor, and T indicate taste or mouthfeel.*

2.3.2 Basic chemistry wine measurements show some correlation to sensory regionality

As a last part of this study, chemical measurements were used to better understand the underlying cause for some of the observed sensory regionality differences. For this, partial least squares regression analysis (PLSR) was carried out to correlate sensory attribute ratings to basic chemistry measurements of ethanol content, pH, titratable acidity (TA), volatile acidity

(VA), free and total SO2 content, residual sugar (RS), malic acid, and growing degree days (GDD). Chemical measurements of the wines are summarized in Appendix Tables 3 A-D.

We assumed that certain sensory attributes, e.g., sweet taste, would be better modelled by the basic chemical measurements compared to complex aroma and flavor attributes. As expected, all three basic tastes (sweet, sour, bitter) and the two mouthfeel attributes (astringent, warm/hot) were found to be well modelled within two dimensions, as indicated by minimal prediction errors evaluated by cross validation.

Including all wines, i.e., all vintages and both varietals, the PLSR model was able to explain 72.5-94.6% of sweet taste, 74.5-88.6% of the sour taste attribute, 63.6-89.2% of bitterness, 77.0-92.0% of the astringent mouthfeel, 48.6-77.4% of the warm/hot attribute, and 32.9-57.0% of the viscous attribute (only measured in the second year) variation. It should be noted that no volatile compounds were measured, thus, no aroma or flavor attributes were found to be well modelled by the chemical data other than those directly linked to the chemical variables (i.e., ethanol aroma and flavor). Sensory and chemical measurement variables that were modelled sufficiently well (i.e., between 60-100% of variance explained by the PLSR model) are described below.

Examining the correlation plots for both years and varieties (Figure 2.3), in all four instances, residual sugar content (RS) is highly positively correlated to sweet taste, along with the honey and grape flavor attributes. Additionally, sour and bitter taste ratings show a negative correlation to RS in all wines. This correlation drives the separation of the wines along the first dimension, which captures between 20 (RI, year 2) to 27% (VB, year 1) of the total variance of the predictor variable matrix. Along the second dimension of the PLSR, explaining between 21 (RI and VB, year 2) and 37% (VB, year 1) of the total variance of the predictor variable matrix, the models vary between the varieties and years as described below:

For the first year Vidal blanc (VB) (Figure 2.3 B) and second year Riesling (RI) (Figure 2.3 C) wines, the second dimension can be mainly attributed to alcohol percentage. In the first year VB wines (Figure 2.3 B), the warm/hot mouthfeel and chemical flavor attributes are highly correlated to alcohol along the second dimension (Appendix Table 4A). Similarly, in the second year RI wines, warm/hot mouthfeel and ethanol flavor were positively correlated to alcohol and malic acid content, while bready/yeasty aroma and anise flavor showed a negative correlation along the second dimension (Appendix Table 4D), closely associated with GDD and VA.

For the first year RI wines (Figure 2.3 A), separation along the second dimension was primary driven by growing degree days (GDD), titratable acidity (TA) and pH, with none of the sensory attributes falling within the 60-100% correlation circle, except for oxidized aroma, which showed a positive correlation to TA and GDD and a negative correlation to pH. Last, for the second-year evaluation of the VB wines (Figure 2.3 D), separation along the second dimension was driven by free and total SO2 content, with only one sensory attribute (chemical flavor) showing more than 60% explained variance; the PLSR model was able to explain 62% of the chemical flavor attribute in these Vidal blanc wines (Appendix Table 4C).

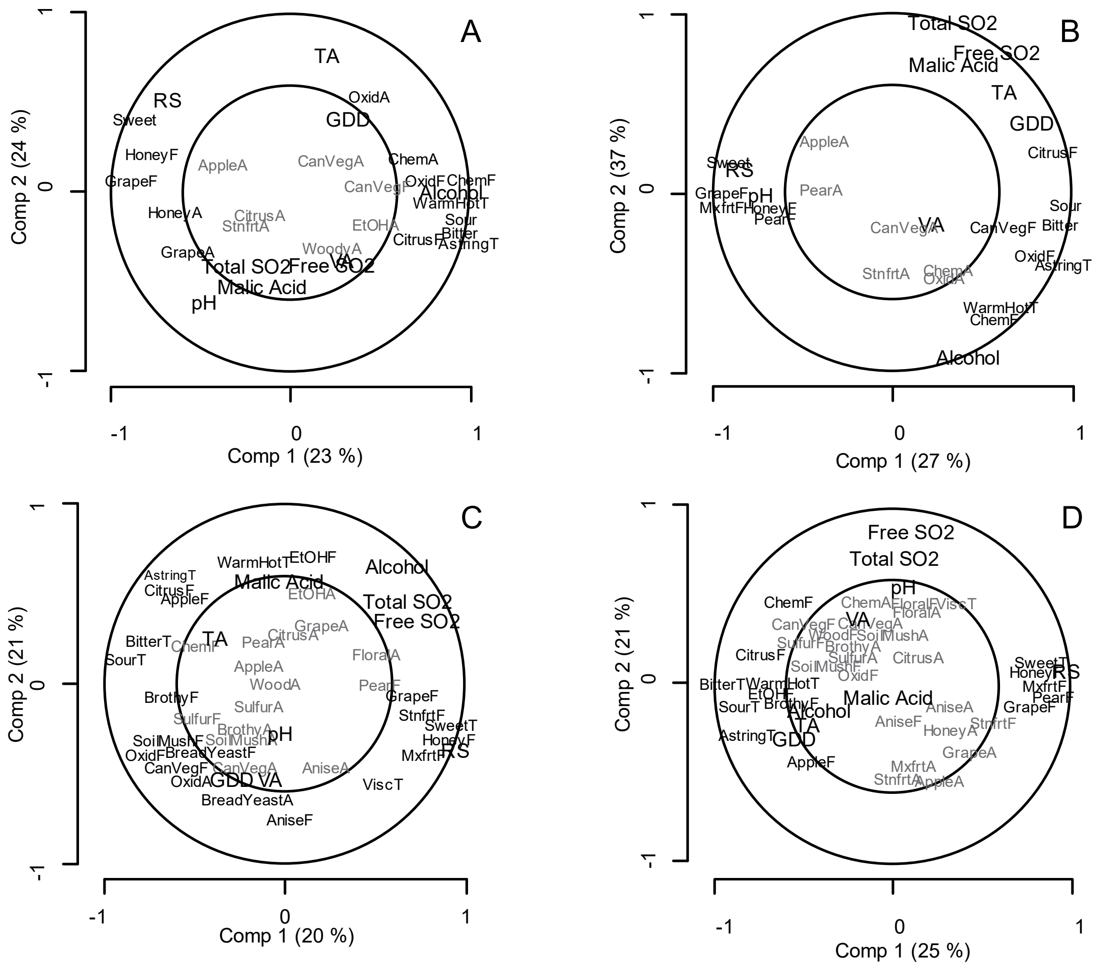

***Figure 2.3**. Partial Least Squares Regression (PLSR) correlation graphs for the four different models, correlating chemical measurements to DA sensory attributes. All predicted sensory attributes showing a correlation of at least 60% are shown in black, otherwise in gray font. (A) first year Riesling, (B) first year Vidal blanc, (C) second year Riesling, and (D) second year Vidal blanc data. Attributes ending in A indicate aroma, F indicate flavor, and T indicate taste or mouthfeel.*

2.4 Discussion

This study provides support of sensory regionality among Pennsylvanian white wines, with main differences attributable to stylistic sweetness differences across regions and varieties: northwestern Pennsylvanian wines trend towards being sweeter, while Riesling wines from the southeast of Pennsylvania are characterized by lower residual sugar content. For the other Pennsylvanian regions, no apparent regional sensory profiles emerged, most likely due to the lower number of samples available from these regions. In the future, a higher sample size would be needed in order to understand the potential for sensory regionality in the southwest, northeast, and central regions of the PA Commonwealth.

While differences were found between each of the regions for each year, it is difficult to attribute these differences to specific terroir or climate factors as there was too much variability in winemaking practices. Instead, stylistic preferences in winemaking was found to drive regional separation, namely between sweeter wines from the northwest and drier wines from the southeast. Differences in the PLSR were expected based on the chemical results, again showing sweetness as the primary separator between wines.

The Riesling wines were more varied in their sensory profiles, with more attributes separating regions than for the Vidal blanc wines. This difference could be explained in several ways, (i) by the difference in sample numbers, as there were more Riesling than Vidal blanc wines in both years, and/or (ii) by the styles of Riesling and Vidal blanc wines common in Pennsylvania (see further discussion below). Finally, the differences could lie in the grape material, and the different expression of sensory regionality between wines made of *V. vinifera* versus interspecific hybrids – this should be further explored.

The northwest region of Pennsylvania hosts most of the grape production in the state. This region, which includes Pennsylvania's coastline with Lake Erie and border with New York, has a dense community of grape-growers and winemakers, as well as the Lake Erie Regional Grape Program run jointly by both The Pennsylvania State and Cornell Universities out of the Penn State Lake Erie Regional Grape Research and Extension Center. The close proximity of these winemakers and grape-growers as well as the nearby institutional resources could be the reason(s) why wines from the northwest showed more similar sensory profiles. One could speculate that wine professionals in this region have a larger impact on each other, through more frequent interactions. Other regions like the southeast have wineries with long-standing histories; however, grape-growing and winemaking in these regions occurs over a larger area. In the northwest region, all of the wines used in this study came from the same county within Pennsylvania. In comparison, there were six different counties within the southeast region that had produced wines for this study. With more geographical space between vineyards, this makes it more difficult to meet and discuss grape-growing and winemaking issues, which in turn could result in less winemaker-driven regional identity of the wines.

Residual sugar levels were not controlled in this experiment, causing the first axis in all PCAs to be driven by sweet taste and other sweet-associated aromas and flavors. This was mirrored in the chemical data, with sweet taste and honey flavor being significantly correlated to the RS content, and negatively correlated to bitter and sour taste. As sweetness can be manipulated by winemakers through back-sweetening, the regional divide seen in Rieslings between sweeter northwest and drier southeast wines again indicates a collective winemaking preference in these regions. The Lake Erie region is known for wines made from native grape varieties, which are known for being produced in a particularly sweet wine style, potentially driving winemaker and consumer choice for sweeter wines. Furthermore, Vidal blanc is often used for sweet ice-wines in the northwest which may influence winemakers towards producing sweeter Vidal blanc wines, as that may be what is expected from this variety.

We found that honey flavor was an important descriptor in separating Vidal blanc wines in the second year of analysis, which agrees with a study on Vidal blanc ice wines: Nurgel et. al. (2004) found differences in Riesling and Vidal blanc ice wines to be defined by oak, honey, raisin, and caramel notes, however this could have been attributed to oak-aged ice wines in the Vidal set. In an aging study on Vidal blanc wines, Chisholm et. al. (1995) reported that fruity notes in Vidal blanc wines changed into more vegetative notes over time. This could explain why significant differences were found between some wines, as vintage was not used as a factor in this analysis, and canned vegetable flavor and aroma were consistently found to be significantly different between regions in both varietals.

Willwerth et. al. (2015) also found that in comparing Riesling wines from different sub-regions in Ontario, that honey aroma and flavor, vegetal aroma, and citrus flavor were all influential in differentiating regions across two vintages. While canned vegetable flavor and aroma was also a significant attribute in differentiating Riesling wines in this study, citrus and honey flavors were seen to be more influential in differentiating the Vidal blanc wines, but were not found to differentiate between the Riesling wines. Last, the same authors also found that sweet, sour, and bitter taste were important attributes in regional differentiation, which was found to be true for all wine samples in this research as well.

This research sets the groundwork for wine regionality in Pennsylvania, though there are many other factors involved that could be also explored. Future works could track the development of these regional profiles over time, using both qualitative interviews and ethnographic research, as well as further quantitative sensory analysis. Developing a regional profile might also be assisted through regular grape-grower and winemaker tasting events where wines from and outside the region could be tasted blindly to develop a “sense of place”.

The current data uses political jurisdiction to separate wines into regions. However, this may have obscured differences relating to climate, elevation, and precipitation. Correlating site-specific climate data on a vineyard level as well as more details on winemaking procedures could help to better understand the differences between wines and better define these regions beyond geographic location. Moreover, standardizing the winemaking and grape-growing procedures could also help to identify which sensory attributes are characteristic to the grapes themselves, and which regional attributes are imparted during winemaking. Future work will include understanding how PA wine professionals perceive their wines, and if time and experience in the wine industry modulates the perception of sensory regionality.

Future work will also study consumer interest and perception of Pennsylvanian wine regions, Pennsylvanian wines themselves, and the effect of location and grape variety on the expectations of wine flavor.

This study was only able to include commercial wines from wineries that were accessible to the researchers by phone or email. The authors understand that this may have biased the samples, as some PA wineries only conduct cellar-door sales and would not have made their wines available for this study. This study also did not screen out faults other than cork-tainted wines. It has been shown that faulted wines or wines perceived as "low-quality" can hide differences in wines (McCloskey et al. 1996). Therefore, some wines may have been incorrectly profiled based on faults or oxidation, especially as sulfur dioxide levels were found to be extremely variable between wines, with free sulfur-dioxide levels ranging from less than 5 mg/L (detection limit) to 65 mg/L. Sulfur dioxide is added as both an antimicrobial and an antioxidant to wines, providing wine stability against oxidation (Waterhouse et al. 2016). This can be exacerbated by high pH wines, which are common in the northeastern US climate (Waterhouse et al., 2016). Sulfites can be negatively perceived by consumers (Costanigro et al. 2014), so wineries may be looking to eliminate sulfites from production, accepting the trade-off resulting in off-flavors, such as oxidized aroma. However, these effects were not seen as prominently in the Vidal blanc wines, where sweetness may have covered or distracted from the oxidized aromas. The storage of wines up to six months at room temperature before serving may also have contributed to these faults, especially if sulfur levels were low.

2.5 Conclusion

This research has found evidence of sensory regionality in commercial Riesling and Vidal blanc wines from Pennsylvania, with the strongest evidence of a solidified regional profile in the northwest region, potentially modulated by winemaking style. Sensory descriptive analysis was also reinforced as a method to identify regional differences between products.

This research explored Pennsylvania as an emerging wine destination where regions may be defined by local signatures and highlights the potential for these regions to differentiate their local products.

Chapter 3

Can Pennsylvanian Wine Professionals Identify Differences in Pennsylvanian White Wines? A Study using Free Sorting

3.1 Introduction

Region of origin has been used to differentiate wines for centuries. Perhaps because of this, wine consumers consider region-of-origin texts displayed on labels an important part of the selection process (Thach 2008), and many wine stores segregate their selections based on regions of origin.

Differences between regions are often attributed to climate and local terrain, but can also be enforced through governmental regulations that often standardize winemaking processes. Winemaking techniques are a fundamental factor in affecting the sensory profile of wine, and thus, also contribute to differences in wine sensory regionality. In locations where governments do not regulate winemaking processes, the winemakers themselves become the gatekeepers of characteristic and distinct regional profiles. Therefore, it is important to understand how well these wine professionals can identify the regional wine profiles that they uphold. Past literature has confirmed that wine professionals (i.e. winemakers, enologists, sommeliers) can group wines by general regional characteristics, as shown for Sauvignon blanc wines from New Zealand, French, and Austria and New Zealand Pinot noir wines (Green et al. 2011b, Parr et al. 2015, Tomasino et al. 2013).

In Pennsylvania, recent research shows that some PA-grown wines exhibit sensory regionality, and that these profiles seem to be mainly affected by post-harvest processing and winemaking styles (see Chapter 2). Based on these results collected by a trained descriptive analysis panel, it is important to test if these differences in sensory regionality of commercial PA-grown white wines would also be identified by PA wine professionals themselves.

Free sorting is a sensory task where individuals group a set of samples by similarity, making judgements based on the perceived similarities and differences between each object in the set. This task is conceptually simple; no prior training except for a brief introduction to the task is needed. Free sorting has been shown to provide similar results comparable to classical descriptive analyses (Cartier et al. 2006). In wine, this method has been used multiple times while working with wine experts (Ballester et al. 2008, Hopfer and Heymann 2014, Parr et al. 2010, Schlich et al. 2015). In addition to the grouping based on similarity, individuals are often asked to name each group or sample, which provides further insight into the perceived characteristics of the samples at hand. Another benefit of using free sorting with product experts in general is the anecdotal evidence that professionals within a field are difficult to re-train in a classical descriptive analysis due to their specific vocabulary. Free sorting allows such individuals to use their knowledge to group samples without any additional training, while providing insight into perceived differences between samples.

There has been much work comparing novice consumers and experts' abilities to discriminate between the same set of products. For a complete review of the literature on expertise and its effect on perception in the wine and beer industry to date, see (Honoré-Chedozeau et al. 2019). As mentioned in this work, Tempere and colleagues have found that training can improve detection thresholds of wine-related odors, and that wine experts perform better than novices at odor detection (Tempere et al. 2011, 2016). While the exact mechanism for improving the odor thresholds through exposure has not been entirely solved, winemakers have a financial incentive to expose themselves to these odorants often. Enhancing their perceptual abilities can have direct effect on their success, even if such training is informal.

In this study we were interested in testing whether PA wine professionals would be able to perceive sensory regionality among wines made from two grape cultivars, as assessed by free sorting. We hypothesize that wine professionals will sort wines into groups that mirror the wine regions in PA, similar to profiles found by classical DA (refer to chapter 2).

3.2 Methods

3.2.1 Samples

Wine samples assessed in two years were collected from Pennsylvania wineries directly. For the first year, 13 Riesling wines (RI) and 10 Vidal blanc wines (VB) were collected, with additional two Riesling and two Vidal blanc wines from out-of-state for comparison, totaling in 15 Riesling wines and 12 Vidal blanc wines in year 1. For the second year of analysis, 20 Riesling wines and 18 Vidal blanc wines were purchased from Pennsylvanian wineries, with two out-of-state Riesling wines and three out-of-state Vidal blanc wines, totaling in a set of 22 Riesling wines and 21 Vidal blanc wines for the second year. In both years, wines were also characterized by a trained panel with classical DA (for more information, see Chapter 2). It should be noted that one winery used as a Pennsylvanian wine in this study was actually produced in Erie, New York, less than 10 miles from the PA border. This sample was labelled a “northwest PA” wine, as it was produced so close to the other wines in the series, and is an influential part of the Lake Erie community.

Wine regions were defined the same way as the Pennsylvania Winery Association (PWA), along county lines (see Figure 2.1), leading to six different wine regions – the northeast (NE), north central (NC), northwest (NW), southeast (SE), south central (SC) and southwest (SW). Table 3.1 summarizes the locations of each set of wines over the two-year analysis, and Appendix Tables 1A-B give more information on the samples for the two years of analysis.

Table 3.1 *The number of different wines included from each region in Pennsylvania across both years and varieties.*

Regions	RI Year 1	VB Year 1	RI Year 2	VB Year 2
NC	1	--	2	--
NE	2	--	1	--
NW	4	3	6	4
SC	2	5	3	6
SE	3	2	8	6
SW	--	--	--	2
Outside PA	2	2	2	3

3.2.2 Year 1

A free sorting task was conducted at two Penn State extension facilities across the state in the spring of 2018, located in Erie, PA and Breinigsville, PA, with wine professionals that were attending a wine extension presentation. Sixteen wine professionals (4 female) attended the tasting at Breinigsville and 20 wine professionals (9 female) attended the tasting in Erie, PA, ranging in age from 21 to over 65 years.

Wine professionals were instructed to taste and expectorate each sample, either the full set of Riesling with 3 additional blind duplicates (18 wines total) or the full set of Vidal blanc wines with 3 additional blind duplicates (15 wines total), and sort them into groups based on similarity. The only explicit instructions were enforcing grouping, with a minimum of two groups (the whole set could not be in one group), and a maximum of n-1 groups (at least one group must have 2 or more wines in it). They could re-taste as needed in order to make their groupings. They were instructed to label each group with a descriptive title of what made those wines similar. Wine professionals were only given one set of wines during the session. Presentation order was randomized, and approximately 15 mL of wine was presented in clear ISO tasting glasses, labelled with random three-digit codes on the glass stem. Glasses were covered with transparent plastic covers, and wines were poured approximately an hour prior to tasting.

3.2.3 Year 2

A free sorting task was conducted with 24 wine professionals (6 female) who came to The Pennsylvania State University in University Park, PA for a Penn State extension enology course, ranging in age from 21 to over 65 years. These wine professionals were given the same instructions as the year before, sorting either the Riesling wines with two blind duplicates (24 wines total), or the Vidal blanc wines with two blind duplicates (23 wines total). Presentation order was randomized, and approximately 30 mL of wine was presented in clear ISO tasting glasses, labelled with random three-digit codes on the glass stem. Wine pours were increased from 15 mL to 30 mL in the second year based on recommendations from winemakers in year 1 to allow repeat tasting. Glasses were covered with transparent plastic covers, and wines were poured approximately two hours prior to tasting.

In both years, wine professionals were asked questions about their occupation, what state or part of PA they worked in, and the extent of their wine tasting routines (i.e. how many wines per day do they test), and were paid $15 for their participation. All data was collected on iPads using Compusense Cloud, Academic Consortium (Guelph, Ontario, Canada). The study was deemed exempt from Institutional Review Board overview based on exempt category 6 (protocol #8551).

3.2.4 Data Analysis

All analyses were run using R statistical software (version 3.6.1, Boston, MA, USA). Free sorting groups were analyzed using DISTATIS for each year and variety. This statistical method allows analysis of the same set of samples (the wines, in this case) to be evaluated by multiple groups (in this instance, the wine professionals), and then create a plot that weighs each individual for a consensus plot that best represents the samples based on the individual groupings, without averaging or losing individual data (Abdi et al. 2012). Barycentric text projection was run on each year and each variety separately as described by (Lahne et al. 2018). Barycentric text projection includes using contingency tables of codes to form matrices that are then projected onto the free sorting maps. A detailed description of the theory behind this process can be found in (Lahne et al. 2018). This process used the DISTATIS and PTCA4CATA R packages (Abdi et al. 2007, http://github.com/HerveAbdi/PTCA4CATA).

3.3 Results

3.3.1 Wine Professionals

Wine professionals were defined by this study to be those interested in attending extension workshops put on by Penn State that were focused at the wine industry. Wine professionals in attendance between both years was 60 in total, with 36 the first year, and 24 the second year. Wine professionals were asked where they were located in Pennsylvania, as well as what occupations they held in the industry and how long they had been in the industry. This information is summarized in Table 3.2. Wine professionals indicated a variety of industry experience from less than one year to over 20 years, though there was a slight skew (52%) towards less time in industry (0-7 years). The occupations were quite evenly spread through many categories, including grape grower, head winemaker, assistant winemaker, winery owner, and tasting room associate. Professionals were allowed to indicate multiple occupations based on all that applied to them, including the “Other” term. “Other” occupations written in by the participants themselves included amateur and home wine makers, wine judges and tasters, researchers, tasting room managers, wine specialists and consultants, and wine ambassadors and aficionados. Some wine professionals indicated that their main work involved being outside of PA (especially in the Erie group, as some were located in New York). However, as they were attending a PA workshop, these professionals were assumed to have some business in the PA wine industry, and their data was therefore used in the analysis. Wine professionals also ranged in region, with all six Pennsylvanian wine regions being represented, though the northwest and south central were the most represented due to the Erie, PA and Breinigsville, PA workshops being heavily attended by professionals of these regions respectively.

Table 3.2. *Information gained by self-reporting wine professionals on their role in the industry.*

Category	Response Option	Count	Percentage
Occupation	Head Winemaker	15	25%
	Assistant Winemaker	15	25%
	Winery Owner	15	25%
	Grape Grower	17	28%
	Wine Purchaser	2	3%
	Grape Purchaser	7	12%
	Cellar Worker	12	20%
	Tasting Room Associate	15	25%
	Sales or Business Manager	10	17%
	Other	11	18%
Region of Work	Northwest	19	32%
	North Central	2	3%
	Northeast	3	5%
	Southwest	6	10%
	South Central	14	23%
	Southeast	7	12%
	Other	9	15%
Years in Industry	Less than 1 year	3	5%
	1-3 years	15	25%
	4-7 years	13	22%
	8-10 years	8	13%
	10-15 years	7	12%
	15-20 years	5	8%
	Over 20 years	9	15%

3.3.2 Descriptor words

Descriptors for each group provided by wine professionals were pre-processed by correcting spelling errors and separating each group label into individual ideas. The words were then coded by three independent coders. These coders then discussed and analyzed the three coding schemes and agreed upon one scheme collectively. Due to the high number of descriptors and codes, a cut-off was used when projecting the words onto the sorting plots via barycentric text projection. Individual frequency plots of coded terms were constructed based on how many times they were used for a specific year and variety, and a drop in term use was found at 20 times. Therefore, terms were kept if they were used at least 20 times per year and variety. A table of the terms used and their frequencies are found in Appendix Table 5.

Descriptor words that had both intensity and quality attributes were given multiple codes, for example, “smells bad” would be coded “aroma” and “bad”, and “slight floral” would be coded “low intensity” and “floral”. This caused general words such as “Aroma” and “Flavor” and certain intensity codes to appear on the text projection maps. The codes for Sweetness and Acidity were, however, coded with their intensities. These attributes were found to be of importance in the descriptive analysis in separating the wines, and therefore, were combined with their intensity moderators to form a single code. For example, “moderate acidity” was coded as “acid/med”, and “sweetest” was coded as “sweet/high”. Other codes were given multiple codes if they indicated multiple ideas. For example, “Citric” indicated both an acid component, and a citrus/fruity component, giving it both an “Acid” code and a “Fruity” code. A table of the words used by wine professionals used to make up each code used in the barycentric text projection is given in the appendix (Appendix Table 6).

3.3.3 Free Sorting

Analyzing sorting data includes calculating co-occurrence matrices based on how many times one sample was sorted into the same group with every other sample. These matrices were projected into a two-dimensional space and plotted, so that wines that appear close together were grouped together more closely than wines further apart using the first two dimensions. Ninety-five percent confidence intervals were then plotted via bootstrapping around these consensus positions, and the resulting maps are shown in Figure 3.1 A-D.

Among the two years and two varieties, the first dimension explained 23%-35% of the total variance in sorting, and the second dimension explained 7%-11% of the total variance. Blind duplicates, indicated by stars in Figure 3.1 A-D, were generally positioned close together, showing consistency in the sorting tasks. Among the four plots, the Riesling replicates from the southeast in year 1 (Figure 3.1 A) were furthest apart, however this difference only affected one dimension, as the points were closely related on the Y axis.

In the first-year sorting of Riesling wines (Figure 3.1 A), the plot seemed to divide into a sweet-dry x-axis, and somewhat towards a good-faulty y-axis. the southeast wines grouped close to the descriptor “dry”, and were close to each other along the x-axis, though spread along the y-axis. The northwest Rieslings were slightly more scattered, with two samples grouping together close to the descriptor “sweet”, while the other two wines from the northwest were spread on the x axis. The non-Pennsylvanian wines were positioned together near the “good” descriptor. Of the other regions shown, the north-central wine grouped closely to the southeast wines near the “dry” term, and the south-central wines were spread, with one grouping with the “dry” term and the southeast wines, and the other trending towards the “faulty/off” term. The northeast wine, in replicate, was positioned close to the northwest wine grouping, close to the terms “sweet” and “fruity”.

In the first-year sorting of Vidal blanc wines (Figure 3.1 B), the plot seemed to be driven again by a sweet-dry x-axis, however the y-axis separation is unclear, ranging from “sweet” and “dry” in the negative dimension to “acid” and “sweet/med” in the positive dimension. In this plot, the southeast wines were very spread across all quadrants of the map, in contrast to their grouping in the first year Rieslings. The northwest wines were grouped closely along the x-axis in the “sweet” dimension. The south-central wines were split, with two wines positioned very close together in this plot, towards the “dry” term, and one wine towards the “sweet/med” part of the plot. The non-Pennsylvanian wines were not positioned very closely in this plot, though they were all in the positive dimension of the y-axis.

In the second-year sorting of Riesling wines (Figure 3.1 C), the x-axis, while explaining the majority of the variation, was not well defined, though it seemed to be separated by an extremely positive “dry” and “acid” dimension, while “fruity” was slightly negative. The y-axis was driven by a “dry” and “fruity” positive axis, and a “bad” negative axis. The southeast region grouped mainly to the positive “dry” x-axis with one notable exception, however, they were quite variable on the y-axis. The northwest region was mainly defined by the “fruity” and “appearance” codes on the positive side of both axes, with one exception. The two north-central wines grouped very closely together on the negative side of the x-axis, in opposition to “dry” and “acid”. The south-central wines were grouped in the exact opposite side to the north central, grouping closer to the “dry”, “acid”, and “appearance” codes. The non-Pennsylvanian wines were not positioned very close together, and the one northeast wine was positioned close to the north-central wines, in the negative portion of the x-axis.

In the second year sorting of Vidal blanc wines (Figure 3.1 D), the x-axis was again a sweet-dry axis, though in this plot “sweet” and “dry” were also partially driving the y-axis, with the y-axis being additionally driven by “fruity” and “low intensity” on the negative side, and “faulty/off” and “bad” on the positive side. Here, the southeast wines have very little grouping, appearing all over the map. The northwest wines, however, were grouped very closely together on the “sweet” side of the x-axis, but the “fruity” “low intensity” “dry” side of the y-axis. The south-central wines were not very close in position to each other in this graph. The southwest wines were grouped on the positive dimension of the y-axis, which was attributed with “bad” and “faulty/off”. The non-Pennsylvanian wines grouped on the x-axis of this graph, but ranged in y-axis.

Overall, some grouping based on region exists, but it is not distinct. The northwestern wines seem to be generally close together across all graphs, consistently trending towards the sweeter and fruitier dimensions. The southeast wines have some grouping in the Riesling wines towards the drier dimensions, but this grouping is not mirrored in the Vidal blanc wines, which were quite variable. The south-central region wines grouped closely in the Riesling wines, and trended towards the dry terms. There does not seem to be a trend with the non-Pennsylvanian data. In year two, when more than one Riesling from the north-central region was included, there was consistent grouping, but attributes did not seem consistent between years, as the first-year wine trended towards “dry”, and the second-year wines were directly opposed to the “dry” term. However, it is important to note that these were all described by different wine professionals, so the concept of the codes (“sweet”, “dry”, “acid”, “fruity”, “faulty/off”, “bad”, etc.) may be slightly different in each graph.

Wine professionals seemed to sort wines similar to the profiling from the descriptive analysis panel, showing that they did find some difference between wines. Like the descriptive analysis on these wines, the northwest region groups together consistently towards the fruity and sweeter dimensions, with only a few outliers. The southeast Rieslings did group together in the first year and second year, again, mirroring the DA results. However, in the sorting, as compared to the descriptive analysis, the south-central group was more distinct, with consistently dry Riesling wines.

The concepts used to separate these wines were mainly based on differences in sweetness or dryness, goodness or badness, the existence of faults, the qualities of smell or flavor, and their intensities. This can be seen in the sorting maps, with three of the four years being separated along the dichotomy of “dry” and “sweet” (Year 2 Rieslings were not described as “sweet” over 20 times by wine professionals), mainly appearing in the first dimension, but in some cases driving the second dimension as well.

The “faulty/off” code was found in every plot. This result makes sense, as there was no screen for faulty wines, and wine professionals often judge wines based on the presence or absence of certain known "faults" in daily practice, and so are trained for these aromas over others. The frequency of this code may also be due to the coding method used. When a term that is frequently used as a wine fault was used by a wine professional (i.e. Oxidized, Burnt Rubber, Plastic, Garlic), this description would receive two codes – the code based on the descriptor itself as well as the faulty/off code. For example, a wine described as "Oxidation" would get an "oxidized" code as well as the "faulty/off" code.

The "fruity" term also appeared in every plot, indicating that this concept was important to the wine professionals. This makes sense when evaluating white wines, which often elicit fruity sensations, though Riesling is not particularly known for its fruity notes, but rather for floral aspects (Jackson 2009). This may be due to the expectation that white wines will be fruity, or that wines are often described by different fruits, and less frequently described by flowers (i.e. "strawberry" is much more common in tasting notes than "rose"). Acid also appeared in every plot, which is congruent with the descriptive analysis which found significant differences in sourness between wines. This code was found independent of sweetness and dryness, showing that wine professionals find these to be separate constructs, and important to note in describing wines.

In three of the four plots, a value judgement code appeared (either "good" or "bad", with year 1 VB having neither). This was not expected, as wine professionals are often cited for using less hedonic judgements in their descriptions (Croijmans and Majid 2016, Honoré-Chedozeau et al. 2019, Hopfer and Heymann 2014). However, this may be due to the existence of faults (i.e. "bad" = "faulted"), and in the three plots, "faulty/off" and "bad" appear extremely close together, or "faulty/off" and "good" are directly opposed. These "good" and "bad" terms may also be more commonly used by professionals in the PA industry. A needs-survey from 2014 in the PA wine industry shows that winemakers indeed do not consider themselves trained professionals, but instead as hobbyists or experienced (those not formally trained but having some years of experience in the industry) (Gardner et al. 2018), however, these winemakers were self-selected and may not be representative of the industry as a whole. Wine professionals in PA might have a different vocabulary than those in more well-known regions.

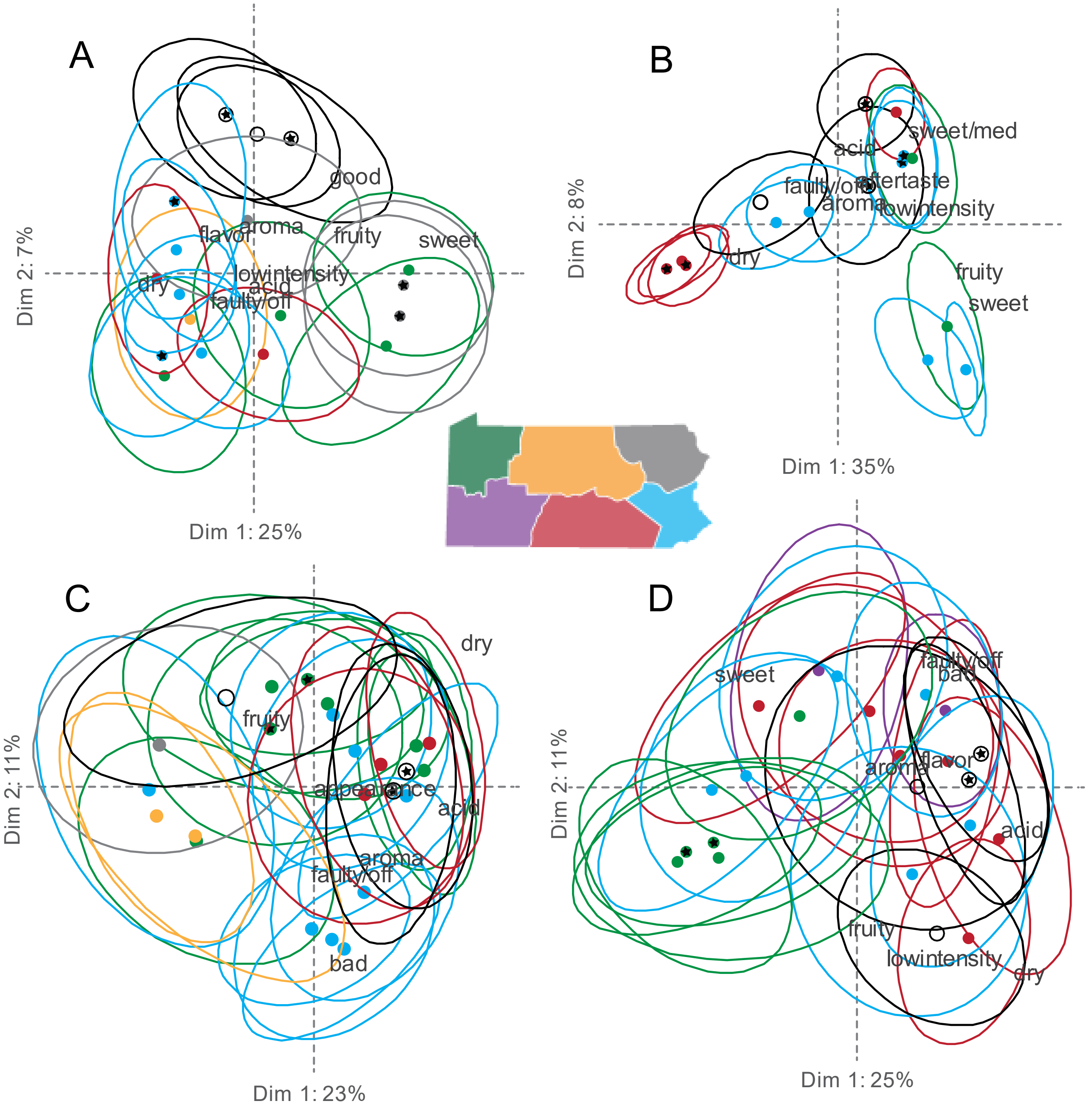

Figure 3.1 A-D. *DISTATIS plots of sorted wines separated by variety and year. Year 1 Riesling (A), Year 1 Vidal blanc (B), Year 2 Riesling (C) and Year 2 Vidal blanc (D). Regions are colored as shown by the map of Pennsylvania. Stars indicate blind duplicates. Codes projected were used 20 or more times.*

3.4 Discussion

Comparing the free sorting maps (Figure 3.1 A-D) to the descriptive analysis plots (Figure 2.2 A-D) similar groupings are found, indicating that Pennsylvanian wine professionals can perceive differences in aroma, taste, and flavor aspects of the assessed wines similar to those of the trained panel. We also see that the wine professionals showed less discrimination between their samples. This was expected, as free sorting tasks do not show as detailed results as those from a DA due to conceptual differences between the tasks, and the fact that attributes are not directly quantified (Cartier et al. 2006, Chollet et al. 2014, Courcoux et al. 2015). Additionally these differences may have been found due to the (i) lack of training and group alignment with regards to descriptors, (ii) varied experience of the participating wine professionals in occupation, years in industry, as well as wine evaluation practice, and (iii) possible fatigue of the participants due to the high number of samples (from 15-23 wines).

Despite the differences in professional experience, ranging from less than one year to over 25 years in the industry, as well as the wine professionals' spread over all six of the PA wine regions, no grouping among wine professionals was found. This was surprising, as previous work indicates that wine professionals are better in differentiating and are more familiar with wines from the region where they work (Grohmann et al. 2018). Smaller sample sizes of assessors may have washed out any potential regional familiarity effect for the wine professionals, indicating that a more extensive study with wine professionals sampling multiple sets of the same wines over a few days could allow for inter-panelist comparisons. There also may be a lack of familiarity as a result of working in an emerging wine region such as Pennsylvania, where wine professionals may rely on educational resources developed for more commonly produced wines and wine regions. In the needs assessment study mentioned above, along with the varied amount of formal training, winemakers reportedly gained most of their information from each other, more than any formal professional development (Gardner et al.

2018). Therefore, the nature of wine-specific education received (the quality of formal and informal instruction) may vary extensively from professional to professional within the industry, which may be a confounding factor to any regional or experiential differences. The variation in the occupations of the wine professionals who participated, from head winemakers and winery owners to tasting room associates and wine aficionados, could also be leading to these differences.

The words and concepts used by participants were often used to compare wines within a set – words like “sweeter”, “more”, and “less than” occurred often. Additionally, congruence was difficult to assess -for example, some wine professionals use the word “dry”, while others use the word “sweet”. “Dry” and “Sweet” are often considered opposites, such as in *Wine Tasting: A Professional Handbook* (Jackson 2009), however “dry” may denote other side-qualities (such as astringency, bitterness, sourness, or lack of fruity aroma), and therefore may not be completely congruent with the absence of sweetness. Without formal training the meaning of the word “dry” may be confusing in itself, as it often is in popular opinion (Teague 2019). Further work could include interviews or focus groups with Pennsylvanian wine professionals, to better understand how they use language to describe wines, and if this use is consistent.

Participants used iPads to give responses. Researchers observed some panelists having difficulty typing on these devices, and group names may have been more comprehensive if using other methods of data collection. As (Lahne et al. 2018) mentioned, check-all-that-apply (CATA) descriptors may also be useful in future studies. In past literature, lists of descriptors have been used instead of or adjacent to free word generation during sorting (Fleming et al. 2015, Lelièvre et al. 2008), and this method may be more applicable or easily performed when using small sample sizes or when one is unable to run replicates, as was true with this study.

There was no outright mention of regions by the wine professionals. While there may have been separation by region, it was not acknowledged as such. Even though colloquially these differences are discussed, they are most likely not linked to specific descriptors because a lack of information, data, or collective agreement upon how PA wine regions differ. This work should be followed by a guided sorting task asking winemakers to sort wines by region to find if these regions are known by wine professionals. If wine professionals are told to sort the wines by PA region, they may group the wines differently. This guided sorting would give more insight into what PA wine professionals think of each region in the state, and what they think represents wines from a certain region.

3.5 Conclusions

This research provides evidence that the free sorting task mirrored the descriptive analysis data, finding that some regionality may exist in Pennsylvania wines. However, there is not enough evidence to conclude that the regions were acknowledged or recognized by wine professionals. Further studies could use informed sorting tasks in order to see if PA wine regions are recognized, specifically the northwest, south central, and southeast, which appeared to show semi-distinct regional profiles.

Chapter 4

Conclusions

4.1 Overall Conclusions

While sensory regionality has been found in Pennsylvanian wines, it does not seem to be extremely distinct, with some overlapping of characteristics in each region. A trained descriptive analysis panel found that the northwest region of the state had the most promise of regional sensory fingerprints in both the studied Vidal blanc and Riesling wines, while wines from the southeast region showed some regionality in the Riesling wines studied. The northwest wines, with the most consistency, were found to be higher in sweet and fruity aromas and flavors overall, while the southeast Riesling wines were characterized as drier.

Pennsylvanian wine professionals did seem to mirror these regional profiles found in the descriptive analysis panel with their sorting maps, indicating that these regional sensory differences are able to be perceived by members of the wine industry as well. The group of wine professionals also found some typicity for wines from the south-central region, previously not found in the descriptive analysis results. However, none of the wine professionals tested used terms associated with region to describe their groups, indicating that these regional differences may be perpetuated unconsciously by the industry.

The conjoint analysis of over a thousand consumers in the mid-Atlantic region found potential for marketing wine regionality for Pennsylvanian wines, and that consumers seem interested in wine label information, though they were mainly concerned with the text indicating wine type (i.e. *Vidal Blanc* vs. *White Wine*) as indicated by higher utility and importance scores. However, some interest in regional text on the label supports the hypothesis that regionality may increase interest in PA wines, as the more generalized regional text (*Proudly produced in Lehigh County, PA*) had higher utility scores than the state text or specified AVA designation.

4.2 Recommendations for the Industry

We have found that the main difference between wines from different regions seem driven by the stylistic preferences of the winemaker. The sweetness of wines seemed to be a large differentiating factor between regions, which is a decision that each producer makes for themselves. While there may be certain qualities of fruit from the northwest region that cause winemakers to make sweet wines, the decision for sweetness still originates from the production of the wine, regardless of fruit characteristics.

However, the findings of this research make the argument that collaboration between winemakers, inherent to the northwest region based on sheer proximity to each other in the small strip of land adjacent to Lake Erie, could be beneficial in promoting a characteristic sensory profile of a region. Indeed, as (Gardner et al. 2018) found, the industry's winemakers indicated that the majority of winemaking education is provided by other local wine industry members. By creating a network of wine professionals within a region, and conducting regular discussions and tastings of both the regions' wines and the wines outside their region, the exchange of knowledge and ideas could enhance the uniqueness of a specific locale. Further, winemakers within a region could use these events to discuss and decide on a regional profile for their wines that could set them apart from other regions.

Additionally, this study revealed that winemaking best practices seem to vary between different wineries. Oxidation, sourness, bitterness, and vegetal notes found by the descriptive analysis, as well as faulty/off flavors found by winemakers show that currently, Pennsylvanian wines are not consistent in wine quality. These findings were also supported by the basic wine chemical analysis. This inconsistency must be addressed before advancing into the greater regional industry – faulty wines will never be accepted in a fine-wine context. Pennsylvania has significant potential with their grape-growing conditions and eager winemakers and advancing governmental policies, but the ability for all PA winemakers to create a quality wine that can last on a grocery shelf will be influential for the future of the region.

It should also be noted that the wines analyzed were separated by political jurisdiction as perpetuated by PWA. However, these regions are strictly divided by county line, and may not accurately represent the different growing regions throughout the state. If regionality is an avenue that wine professionals in PA want to address, understanding true wine regions through analyzing other factors like climate, elevation, and soil type will be important.

4.3 Future Work

This study is just the beginning of sensory research on Pennsylvanian wines. Other research could investigate how wines from these regions differ from each other if winemaking procedures are controlled.

Ethnographic research could be conducted with winemakers across the state to better understand what drives their decisions in winemaking processes, where inspirations are drawn from, and what the needs are for winemakers in order to increase the quality of wines in PA, and thus the success of the industry.

There is also plenty of opportunity for consumer work, in order to better understand why consumers choose the wines they do, and how to introduce consumers to Pennsylvanian wines. Consumer sensory studies could give insight into how and why Pennsylvanian consumers perceive the wines as they do. Also, content or semiotic analysis could be done on the wine labels currently available in Pennsylvania, in order to better understand the current market, and to understand the consumer ideal in regard to the Pennsylvanian label.

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Appendix

Chapter 2 Supplementary Tables

Appendix Table 1A. *Year 1 wine samples and their wine type, vintage, reported region, retail price in USD (before tax), and closure type.*

Wine Number	Wine Type	Vintage	Region	Price	Closure
1	Riesling	2016	NW	14.95	Screw Cap
2	Vidal blanc	2015	SE	11.99	synthetic Cork
3	Vidal blanc	2016	SE	11.99	Synthetic Cork
4	Vidal blanc	2015	SC	10.95	Screw Cap
5	Riesling	2015	NC	_	Screw Cap
6	Vidal blanc	2015	SC	_	Natural Cork
7	Vidal blanc	2016	SC	12.90	Agglomerated Cork
8	Riesling	2016	NW	_	Screw Cap
9	Vidal blanc	2016	SE	_	Agglomerated Cork
10	Vidal blanc	2016	NW	_	Synthetic Cork
11	Riesling	2016	SE	_	Agglomerated Cork
12	Riesling	2016	SC	_	Natural Cork
13	Riesling	2016	SE	_	Screw Cap
14	Vidal blanc	2016	SE	_	Screw Cap
15	Riesling	2015	NW	_	Synthetic Cork
16	Vidal blanc	2016	NW	_	_
17	Riesling	2016	SE	13.99	Synthetic Cork
18	Vidal blanc	2016	SE	_	Screw Cap
19	Riesling	2016	NW	14.15	_
20	Riesling	2015	NE	_	Synthetic Cork
21	Riesling	2015	NE	_	Synthetic Cork
22	Riesling	2016	SC	_	Natural Cork
23	Riesling	2016	SE	_	_
24	Riesling	2016	NY	_	_
25	Vidal blanc	2015	NY	_	_
26	Vidal blanc	2016	VA	_	_
27	Riesling	2015	WA	_	_

Appendix Table 1B. *Year 2 wine samples and their wine type, vintage, reported region, retail price in USD (before tax), and closure type.*

Wine Number	Wine Type	Vintage	Region	Price	Closure
1	Riesling	2017	NW	_	_
2	Riesling	2017	NW	15.09	Natural Cork
3	Riesling	2017	SE	21.00	Synthetic Cork
4	Riesling	2017	NW	_	_
5	Riesling	2017	NW	14.99	_
6	Riesling	2017	SE	15.99	_
7	Riesling	2017	SE	12.49	_
8	Riesling	2016	SE	18.00	_
9	Riesling	2016	SE	13.99	Synthetic Cork
10	Riesling	2017	NE	16.00	_
11	Riesling	2017	SC	18.00	Natural Cork
12	Riesling	2017	SC	_	_
13	Riesling	2017	SE	_	_
14	Riesling	2017	NC	10.38	_
15	Riesling	2017	SC	_	Natural Cork
16	Riesling	2016	NW	15.00	_
17	Riesling	2017	NC	16.04	_
18	Riesling	2017	SE	18.00	_
19	Riesling	2017	NW	14.95	_
20	Riesling	2017	SE	12.99	_
21	Riesling	2017	NY	15.99	_
22	Riesling	2016	WA	11.99	_
23	Vidal blanc	2017	SE	_	Screw Cap
24	Vidal blanc	2017	SE	_	_
25	Vidal blanc	2017	SW	18.00	_
26	Vidal blanc	2017	SC	_	_
27	Vidal blanc	2016	SC	_	_
28	Vidal blanc	2017	SC	_	Natural Cork
29	Vidal blanc	2016	SW	18.00	_
30	Vidal blanc	2017	SE	12.49	_
31	Vidal blanc	2017	SE	11.99	Synthetic Cork
32	Vidal blanc	2017	SE	13.00	_
33	Vidal blanc	2016	NW	10.95	_
34	Vidal blanc	2017	SC	_	Agglomerated Cork
35	Vidal blanc	2017	NW	15.00	_
36	Vidal blanc	2017	NW	14.15	Natural Cork
37	Vidal blanc	2017	NW	_	_
38	Vidal blanc	2017	SC	17.00	_
39	Vidal blanc	2016	SC	_	_
40	Vidal blanc	2016	NY	12.99	_
41	Vidal blanc	2017	VA	_	_
42	Vidal blanc	2016	NJ	14.00	_
43	Vidal blanc	2017	SE	_	_

Appendix Table 2A. *Means and LSD values for all significant attributes in the DA of Vidal blanc wines from the first year of research.*

Wine Code (VB-)	02-SE	03-SE	04-SC	06-SC	07-SC	09-SE	10-NW	14-SE	16-NW	18-SE	25-NY	26-VA	**LSD**
Aromas													
Apple	1.86	1.61	2.37	1.76	1.41	2.36	2.20	2.33	1.86	1.96	1.63	2.50	**0.73**
Pear	1.26	1.28	1.86	0.80	0.90	1.36	1.37	1.26	1.10	1.13	1.05	1.57	**0.60**
Stonefruit	1.08	0.96	0.64	1.12	0.94	0.88	1.54	0.52	1.17	0.88	1.00	0.87	**0.53**
Oxidized	2.84	1.87	1.66	2.20	1.95	2.25	1.70	2.00	2.39	2.05	2.24	2.19	**0.69**
Chemical	2.25	1.45	1.71	1.13	1.68	1.37	1.12	1.25	1.24	1.36	1.36	1.61	**0.63**
Canned Vegetable	1.22	0.88	0.29	1.11	0.51	0.59	0.71	1.10	0.80	0.59	1.47	0.49	**0.61**
Flavors													
Pear	1.02	1.25	1.44	0.60	0.45	1.01	1.41	1.11	1.12	0.38	0.67	1.21	**0.51**
Grape	1.83	2.26	2.18	1.57	1.60	2.30	2.47	2.29	2.47	1.37	1.61	2.00	**0.57**
Mixed Fruit	0.88	1.04	0.87	0.56	0.51	1.01	1.19	1.09	1.16	0.30	0.74	0.64	**0.74**
Citrus	0.93	0.49	1.03	1.36	1.32	0.38	0.65	0.55	0.71	1.80	1.12	0.92	**0.55**
Honey	1.28	1.68	1.39	1.04	0.87	1.81	1.43	1.76	1.34	0.69	1.00	1.33	**0.52**
Oxidized	2.73	1.99	2.22	2.58	2.08	1.74	1.69	1.58	1.77	2.50	2.31	2.17	**0.62**
Chemical	2.73	1.99	2.22	2.58	2.08	1.74	1.69	1.58	1.77	2.50	2.31	2.17	**0.66**
Tastes & Mouthfeels													
Sweet	2.07	4.07	3.35	1.74	1.74	5.00	4.36	4.98	4.12	1.36	2.36	2.63	**0.88**
Sour	3.56	1.68	2.63	3.87	3.67	1.63	1.94	1.54	2.04	4.27	3.47	3.29	**0.93**
Bitter	2.36	0.91	1.11	2.51	2.79	0.83	1.08	0.57	1.17	2.50	1.78	1.64	**0.95**
Astringent	3.80	2.31	2.70	3.41	3.54	1.61	2.16	1.43	2.33	3.26	3.02	3.22	**0.72**
Warm/Hot	4.81	3.56	3.62	3.88	4.22	3.69	3.59	2.67	3.50	4.01	3.78	4.36	**0.80**

Appendix Table 2B. *Means and LSD values for all significant attributes in the DA of Riesling wines from the first year of research.*

Wine Code (RI-)	01-NW	05-NC	08-NW	11-SE	12-SC	13-SE	15-NW	17-SE	19-NW	20-NE	21-NE	22-SC	23-SE	24-NY	27-WA	**LSD**
Aromas																
Apple	1.74	1.91	1.99	2.12	1.40	2.34	1.64	1.50	1.97	2.34	1.42	1.55	1.08	2.02	1.69	**0.60**
Grape	1.79	1.53	1.99	1.71	1.96	1.80	2.09	1.25	2.00	1.68	1.34	1.15	0.79	2.03	1.68	**0.53**
Stonefruit	1.26	0.49	0.83	1.21	0.95	0.81	1.43	0.88	1.00	0.89	0.74	0.85	0.58	1.16	0.99	**0.49**
Citrus	0.68	0.55	0.63	0.76	0.44	1.03	1.02	0.82	0.86	0.63	0.63	0.42	0.41	0.74	0.45	**0.44**
Honey	1.10	0.79	1.41	1.31	1.01	0.96	1.16	0.85	0.98	1.13	0.81	0.95	0.51	1.09	1.03	**0.37**
Oxidized	2.00	2.74	2.03	2.11	1.71	1.96	1.94	2.37	1.86	2.34	1.87	2.97	2.89	2.14	1.89	**0.60**
Ethanol	2.32	2.36	1.94	1.72	2.05	2.47	1.71	2.61	1.84	2.03	1.59	1.50	2.47	1.80	2.06	**0.62**
Chemical	1.36	1.63	1.08	0.71	0.98	1.88	0.95	2.33	1.17	1.31	1.23	0.97	3.09	1.09	1.07	**0.72**
Canned Vegetable	0.37	1.04	0.36	0.42	0.34	0.50	0.60	0.91	0.44	0.46	0.76	1.05	0.56	0.33	0.30	**0.40**
Woody	0.57	0.73	0.54	0.68	0.80	0.55	0.62	1.00	0.68	0.40	0.69	0.78	0.69	0.39	0.54	**0.31**
Flavors																
Grape	1.74	1.50	2.61	1.91	1.59	1.78	2.10	1.79	2.32	2.23	1.73	1.76	0.70	2.31	2.09	**0.52**
Citrus	1.80	1.16	0.62	1.66	1.46	1.70	1.15	1.63	0.96	1.22	1.32	0.75	1.91	1.00	0.85	**0.56**
Honey	0.96	0.76	1.74	0.73	0.54	0.94	1.37	1.28	1.35	1.02	0.74	1.28	0.46	1.29	0.99	**0.38**
Oxidized	2.32	2.50	1.45	2.13	2.12	2.30	2.01	2.26	1.54	2.13	2.07	2.39	2.36	1.69	2.10	**0.53**
Chemical	1.20	1.88	0.69	1.27	1.29	1.32	1.05	1.43	0.84	1.01	1.30	1.16	2.36	1.32	1.11	**0.43**
Canned Vegetable	0.19	0.50	0.10	0.12	0.14	0.15	0.14	0.43	0.09	0.10	0.29	0.36	0.42	0.09	0.08	**0.24**
Tastes & Mouthfeels																
Sweet	1.74	1.83	4.89	2.03	1.72	2.40	3.51	2.81	4.20	3.93	2.66	3.69	1.19	3.71	3.66	**0.67**
Sour	3.82	3.11	1.48	3.34	3.65	3.60	2.03	3.19	1.61	2.70	2.68	2.44	4.51	2.58	2.52	**0.76**
Bitter	1.84	1.74	0.47	1.64	2.20	1.98	0.93	1.65	0.43	0.79	1.70	0.99	3.05	1.04	0.84	**0.70**
Astringent	3.63	3.27	1.88	3.16	3.21	3.50	2.55	3.43	2.03	2.62	2.73	2.46	3.77	2.43	2.67	**0.67**
Warm/Hot	3.73	3.65	2.56	3.74	3.87	4.10	3.56	4.05	2.56	3.29	3.41	3.84	4.17	3.63	3.85	**0.70**

Appendix Table 2C. *Means and LSD values for all significant attributes in the DA of Vidal blanc wines from the second year of research.*

Wine Code (VB-) *Attributes*	01-SE	02-SE	03-SW	04-SC	05-SC	06-SC	07-SW	08-SE	09-SE	10-SE	11-NW	12-SC	13-NW	14-NW	15-NW	16-SC	17-SC	18-NY	19-VA	20-NJ	21-SE	**LSD**
Aromas																						
Citrus	1.71	2.41	2.24	1.79	1.24	1.50	1.29	1.61	2.25	1.92	1.79	2.10	1.41	1.72	2.48	2.02	1.78	2.01	2.06	1.04	1.94	**0.65**
Stonefruit	2.00	1.44	1.39	2.20	1.60	2.01	1.20	1.34	3.48	1.34	1.81	1.92	1.80	1.69	1.75	2.03	2.08	2.11	1.84	1.11	1.46	**0.81**
Apple	1.83	1.31	1.50	1.54	1.02	1.86	1.18	1.35	1.87	1.63	2.17	1.64	1.43	1.49	1.63	1.32	2.29	2.19	2.02	0.86	1.13	**0.71**
Mix Fruit	2.13	1.86	1.81	1.78	1.31	2.25	1.06	1.18	2.68	1.77	1.49	1.69	2.17	2.17	1.37	2.51	1.79	1.83	1.47	0.77	1.44	**0.85**
Canned Vegetable	2.21	1.04	2.24	1.82	3.13	2.09	3.13	2.34	0.98	1.79	1.34	1.37	1.49	1.44	2.35	1.49	1.31	0.92	1.62	3.42	1.84	**0.75**
Soil/Mushroom	1.45	0.67	1.41	2.01	2.79	1.59	3.66	2.11	0.43	1.76	1.25	1.30	1.26	1.25	2.06	1.14	1.14	0.96	1.48	3.81	1.79	**0.75**
Chemical	1.96	2.56	2.69	2.21	2.35	1.81	2.57	2.99	1.73	2.87	2.44	2.26	2.13	1.61	2.71	2.51	2.58	2.00	2.83	2.18	2.93	**0.75**
Honey	1.92	1.45	1.75	1.74	1.29	2.26	1.14	1.18	2.30	2.02	1.63	2.06	2.79	1.57	1.77	1.93	1.73	1.54	1.10	0.73	1.69	**0.73**
Floral	1.61	4.53	3.51	1.56	1.41	2.05	1.91	1.50	2.13	2.29	2.45	2.31	1.84	1.86	2.34	2.01	2.16	1.99	1.70	1.03	2.09	**0.81**
Grape	1.49	1.82	2.13	1.88	1.08	2.03	0.90	1.58	2.50	1.42	2.22	1.18	3.20	2.04	1.33	2.00	2.25	2.58	1.36	0.83	1.38	**0.76**
Anise	0.54	0.69	0.54	0.83	0.51	0.77	0.61	0.70	1.29	0.60	0.82	1.46	1.47	0.44	0.85	0.61	0.41	0.32	0.34	0.58	0.48	**0.50**
Brothy	0.88	0.46	0.85	0.72	1.44	0.87	1.56	0.97	0.43	0.87	0.78	0.60	0.55	0.74	0.84	0.55	0.69	0.45	0.92	1.51	0.69	**0.49**
Sulfur	0.84	0.40	0.33	0.87	1.89	0.81	1.58	1.07	0.21	0.55	0.61	0.58	0.43	0.72	1.26	0.50	0.35	0.51	1.40	2.27	0.63	**0.57**
Flavors																						
Citrus	3.01	3.06	2.68	2.62	2.35	1.89	2.71	2.32	2.32	1.90	1.78	2.52	1.82	2.06	2.48	2.84	2.67	1.94	2.59	2.20	2.33	**0.59**
Stonefruit	1.23	1.00	1.18	1.94	1.63	1.59	0.74	1.20	2.93	1.62	1.56	1.10	2.00	1.33	1.61	1.01	1.29	1.29	1.67	0.61	1.76	**0.68**
Pear	1.30	1.67	1.61	1.80	1.33	2.37	1.24	1.85	2.09	2.11	2.11	1.05	2.15	1.94	1.99	1.31	1.53	1.88	1.73	0.86	2.06	**0.69**
Apple	2.93	2.30	2.45	2.37	2.12	1.90	2.01	2.55	1.94	1.66	1.99	1.18	1.68	2.13	2.10	2.60	3.01	2.46	3.35	1.40	1.67	**0.82**
Mixed Fruit	1.19	0.99	1.08	1.47	1.37	2.40	0.66	1.39	2.84	2.59	2.08	0.90	2.51	2.04	1.84	0.95	0.89	1.25	1.23	0.50	2.54	**0.76**
Canned Vegetable	0.94	1.17	1.73	0.94	1.30	1.08	1.86	1.40	0.70	0.43	0.70	1.06	0.73	0.65	0.99	1.21	0.86	0.96	0.89	1.83	0.88	**0.53**
Soil Mushroom	1.14	0.86	0.94	1.05	1.19	0.91	1.77	1.46	0.49	1.01	0.69	1.46	0.84	0.79	0.69	0.80	0.97	0.60	0.56	2.53	0.82	**0.62**
Wood	0.89	0.95	0.67	0.68	1.05	0.96	1.23	0.84	0.38	0.67	0.95	1.56	0.71	0.52	0.82	0.62	0.44	0.81	0.71	1.38	0.81	**0.52**
Chemical	2.19	3.26	2.54	2.12	3.19	2.06	2.67	2.48	1.63	2.26	1.83	2.74	2.21	2.00	2.30	2.72	2.64	2.21	2.48	2.91	2.78	**0.70**
Honey	0.98	1.06	1.51	1.81	1.71	3.00	0.85	1.93	2.33	3.70	3.20	1.03	2.98	2.49	2.63	1.16	1.18	0.99	1.38	0.51	2.88	**0.68**
Floral	1.58	4.05	2.56	1.34	1.46	1.59	1.62	1.52	1.92	1.81	1.82	1.94	1.81	1.24	1.86	1.43	1.52	1.61	1.56	0.74	1.79	**0.70**
Ethanol	2.80	2.91	2.47	2.76	3.54	2.05	2.66	2.69	2.36	2.16	2.54	3.11	2.19	2.57	2.34	2.94	3.55	2.77	2.63	2.80	2.78	**0.72**
Oxidized	2.46	2.16	2.13	1.79	1.63	1.27	2.46	2.08	1.83	1.69	2.28	2.28	1.73	2.23	2.20	2.14	1.92	1.64	1.50	2.08	1.49	**0.59**
Grape	1.46	1.26	1.90	2.34	1.33	2.25	1.24	2.12	2.25	2.06	2.74	0.95	3.42	2.20	2.47	1.34	1.48	1.75	1.96	0.82	2.17	**0.68**
Anise	0.36	0.63	0.57	0.63	0.54	0.67	0.65	0.56	0.84	0.60	0.52	1.32	1.01	0.28	0.38	0.48	0.57	0.37	0.38	0.71	0.33	**0.44**
Brothy	0.99	0.75	0.53	0.67	0.91	0.63	1.10	0.90	0.43	0.51	0.46	0.98	0.36	0.53	0.50	1.23	0.62	1.04	0.72	1.66	0.32	**0.51**
Sulfur	0.73	0.70	0.52	0.48	0.84	0.49	0.91	0.64	0.20	0.34	0.35	0.51	0.24	0.47	0.50	0.52	0.61	0.39	0.48	1.80	0.49	**0.48**

Appendix Table 2C continued. *Means and LSD values for all significant attributes in the DA of Vidal blanc wines from the second year of research.*

Wine Code (VB-) *Attributes*	01-SE	02-SE	03-SW	04-SC	05-SC	06-SC	07-SW	08-SE	09-SE	10-SE	11-NW	12-SC	13-NW	14-NW	15-NW	16-SC	17-SC	18-NY	19-VA	20-NJ	21-SE	**LSD**
Tastes & Mouthfeels																						
Sweet	1.82	2.13	3.79	4.38	3.91	5.49	2.30	3.99	5.83	6.79	6.63	1.95	6.48	5.10	6.28	1.88	2.69	2.02	4.27	1.90	6.34	**0.79**
Sour	5.96	5.16	4.83	4.95	4.28	3.73	5.69	4.66	3.46	3.12	2.95	5.21	3.22	3.88	3.76	5.58	4.46	4.54	4.44	4.74	3.19	**0.81**
Bitter	3.69	3.34	2.98	2.91	3.04	2.09	3.97	2.77	2.21	1.70	1.67	3.96	1.96	1.87	2.24	3.30	3.59	2.89	2.39	4.25	1.97	**0.90**
Viscous	1.84	2.03	1.67	1.67	1.79	1.76	1.84	2.12	1.98	2.21	2.26	1.84	2.29	1.56	1.95	1.89	1.92	1.69	1.54	1.95	2.38	**0.47**
Astringent	4.04	3.93	3.84	3.79	4.03	2.36	3.72	3.58	3.31	3.14	3.38	3.83	3.17	3.11	2.99	4.34	4.51	3.63	3.98	4.14	2.89	**0.70**
Warm/Hot	4.16	4.17	3.80	3.98	4.69	3.29	4.10	3.81	3.62	3.45	3.78	3.99	3.41	3.08	3.11	4.36	4.40	3.45	3.98	4.18	3.64	**0.68**

Appendix Table 2D. *Means and LSD values for all significant attributes in the DA of Riesling wines from the second year of research.*

Wine Code (RI-)	01-NW	02-NW	03-SE	04-NW	05-NW	06-SE	07-SE	08-SE	09-SE	10-NE	11-SC	12-SC	13-SE	14-NC	15-SC	16-NW	17-NC	18-SE	19-NW	20-SE	21-NY	22-WA	**LSD**
Attributes																							
Aromas																							
Citrus	1.56	1.19	1.45	1.18	1.65	2.03	1.83	1.39	1.43	1.56	1.61	1.66	2.11	1.40	1.20	1.78	1.27	1.50	2.13	1.04	1.82	1.71	**0.63**
Pear	2.10	2.27	1.19	2.05	2.07	2.11	1.49	1.89	1.20	1.73	1.33	1.47	1.88	0.91	1.54	1.93	3.04	2.33	1.74	1.05	1.28	2.17	**0.84**
Apple	1.42	1.32	1.20	1.33	1.91	1.72	1.45	1.92	1.04	1.26	1.57	1.41	1.78	1.34	1.01	1.81	2.98	2.26	1.98	0.90	1.35	1.94	**0.76**
Canned Vegetable	2.11	2.89	4.54	2.60	1.79	1.83	2.01	1.38	1.86	1.79	2.42	2.39	1.45	2.60	2.45	1.45	1.17	2.16	1.54	3.72	2.31	0.82	**0.83**
Soil/Mushroom	1.39	1.63	3.56	2.23	1.76	1.82	1.55	1.47	2.52	1.89	1.88	2.21	1.44	1.89	2.93	1.33	1.11	1.54	1.22	3.68	2.29	0.83	**0.87**
Woody	1.15	1.13	1.36	1.54	0.96	0.89	0.96	0.93	1.34	1.35	1.61	1.34	0.86	1.18	1.41	1.06	0.70	0.90	0.61	1.90	1.34	0.89	**0.65**
Floral	2.90	1.51	1.41	2.13	2.00	1.81	2.31	1.63	1.81	1.73	1.49	1.79	3.03	2.03	1.91	2.00	1.84	1.42	2.24	1.28	1.69	2.63	**0.85**
Ethanol	1.82	2.41	1.44	2.11	2.43	2.97	2.14	2.01	1.92	2.82	2.74	2.63	2.41	2.41	2.12	2.67	2.26	2.67	2.98	1.93	2.30	3.35	**0.88**
Oxidized	1.94	2.11	3.03	2.52	2.10	1.80	2.33	2.85	1.73	1.31	1.51	1.97	1.65	1.96	1.84	1.93	2.33	2.93	1.68	2.13	2.10	1.36	**0.88**
Grape	1.46	1.53	0.63	1.44	1.72	1.39	2.01	2.16	1.57	1.69	1.61	1.43	1.54	1.24	1.43	2.54	2.50	2.30	1.86	1.13	1.95	2.41	**0.80**
Anise	0.89	1.76	1.02	0.38	0.50	0.32	1.38	0.48	0.51	0.37	0.73	0.49	0.58	0.98	0.64	0.50	0.66	0.64	0.51	0.56	0.64	0.45	**0.54**
Brothy	0.92	1.08	1.43	0.86	0.71	0.83	0.86	0.91	0.94	0.68	0.79	0.98	0.67	1.03	1.05	0.73	0.51	1.08	0.77	2.01	0.99	0.48	**0.49**
Bready/Yeasty	1.02	1.38	2.24	1.10	0.95	1.00	1.06	1.46	1.54	1.04	1.27	1.34	0.96	1.74	1.34	0.97	0.69	1.35	0.67	1.45	0.97	0.76	**0.57**
Sulfur	0.95	0.72	1.43	1.01	0.68	0.99	1.11	0.95	0.92	1.10	1.03	1.28	0.40	0.88	1.12	0.55	0.55	0.61	0.64	2.23	1.21	0.47	**0.60**
Flavors																							
Citrus	2.17	2.51	2.20	2.22	3.44	3.18	1.82	2.31	2.58	2.28	2.85	2.44	3.29	1.67	2.36	2.11	1.92	3.24	2.96	3.02	2.74	2.48	**0.66**
Stonefruit	1.32	0.87	0.98	1.44	0.97	1.22	1.78	1.08	0.73	1.53	1.10	1.74	0.68	1.96	1.21	1.34	1.22	0.66	0.95	0.89	1.14	1.11	**0.66**
Pear	2.26	1.61	1.03	2.48	1.71	2.25	2.24	1.77	1.08	2.21	1.37	1.76	0.88	2.04	1.57	1.91	2.35	1.25	1.20	0.99	1.01	2.01	**0.78**
Apple	2.54	2.42	1.94	2.75	3.56	3.19	1.72	2.94	2.38	2.75	3.09	2.60	2.69	1.32	2.43	1.72	3.30	3.63	2.99	2.14	2.77	3.04	**0.88**
Mixed Fruit	1.95	1.64	0.74	0.84	0.59	0.72	2.93	0.86	0.69	1.63	0.89	1.29	0.62	3.15	1.15	2.20	1.29	0.89	0.94	0.49	0.90	0.89	**0.73**
Canned Vegetable	1.01	1.91	4.11	1.15	1.22	0.98	0.91	1.22	1.16	0.67	0.99	1.74	1.36	0.74	1.39	0.60	1.40	1.43	1.04	2.46	1.51	0.75	**0.67**
Soil/Mushroom	1.14	1.48	2.75	1.03	1.06	0.80	0.88	1.08	1.58	1.03	1.05	1.10	1.01	0.53	2.01	0.63	1.10	1.01	0.91	2.27	1.46	0.63	**0.66**
Chemical	2.44	3.60	2.83	1.96	2.45	2.33	1.87	2.76	3.39	1.98	3.61	2.83	3.29	1.91	2.19	2.12	2.05	2.91	2.97	2.87	2.62	2.36	**0.82**
Honey	1.58	1.33	0.55	1.99	1.08	1.15	3.74	1.72	0.85	2.78	1.03	1.60	1.04	4.48	1.55	2.83	1.66	0.64	1.12	0.93	1.04	1.72	**0.66**
Ethanol	2.30	2.61	1.39	2.09	2.86	3.04	1.89	2.13	2.60	2.15	2.70	3.07	2.24	2.49	2.61	3.08	1.97	2.79	3.19	2.51	2.38	3.13	**0.83**
Oxidized	1.89	2.07	2.93	1.94	1.69	1.93	2.15	2.98	1.89	1.54	1.62	2.31	1.79	1.27	2.10	1.73	2.17	2.60	1.98	2.05	2.07	1.44	**0.79**
Grape	1.54	1.38	0.83	1.71	1.40	1.61	2.58	1.47	1.13	2.33	1.31	1.40	1.43	2.56	1.82	2.31	2.46	1.65	1.62	1.36	1.77	2.31	**0.74**
Anise	0.50	1.00	1.21	0.36	0.31	0.31	1.14	0.50	0.68	0.41	0.62	0.34	0.46	0.72	0.53	0.43	0.48	0.57	0.42	0.46	0.45	0.47	**0.47**
Brothy	0.82	0.92	1.30	0.71	0.59	1.13	0.44	0.87	0.84	0.50	0.66	0.56	0.55	0.51	0.96	0.65	0.72	1.08	0.89	1.29	0.64	1.05	**0.47**
Bready/Yeasty	0.90	1.05	1.70	0.65	0.58	0.98	0.56	0.99	1.17	0.78	1.28	0.76	0.71	0.84	0.99	0.92	0.85	1.06	0.84	1.40	0.91	0.71	**0.46**
Sulfur	0.48	0.83	1.21	0.34	0.53	0.56	0.42	0.62	0.86	0.46	0.49	0.96	0.59	0.49	1.04	0.33	0.39	0.68	0.71	1.25	0.71	0.28	**0.48**

Appendix Table 2D continued. *Means and LSD values for all significant attributes in the DA of Riesling wines from the second year of research.*

Wine Code (RI-) *Attributes*	01-NW	02-NW	03-SE	04-NW	05-NW	06-SE	07-SE	08-SE	09-SE	10-NE	11-SC	12-SC	13-SE	14-NC	15-SC	16-NW	17-NC	18-SE	19-NW	20-SE	21-NY	22-WA	**LSD**
Tastes & Mouthfeels																							
Sweet	5.03	2.58	1.91	4.49	2.51	3.35	7.05	2.83	2.12	5.88	2.43	3.96	2.25	7.90	3.43	5.96	4.79	1.68	2.74	1.91	2.35	5.10	**0.74**
Sour	3.68	4.56	6.31	4.30	5.84	5.43	2.70	4.68	4.68	4.12	5.58	4.32	5.52	2.61	5.09	3.63	3.55	6.27	5.47	6.01	5.19	4.22	**0.84**
Bitter	2.00	3.49	3.64	1.97	3.10	2.80	1.55	3.07	3.50	1.85	3.48	3.41	3.47	1.36	2.25	2.14	1.77	4.33	3.01	4.06	4.23	1.99	**0.85**
Viscous	2.23	1.93	2.23	2.14	1.76	1.73	2.46	1.97	1.72	2.04	2.04	2.28	1.83	2.64	1.83	2.02	1.76	1.88	1.60	1.91	1.79	1.71	**0.47**
Astringent	2.99	4.54	3.21	3.44	4.35	4.20	2.61	4.11	4.55	3.91	4.41	4.58	4.21	2.53	3.62	3.54	3.55	5.17	4.03	4.40	4.49	3.98	**0.75**
Warm/Hot	3.34	4.24	2.65	3.27	4.26	4.08	3.36	4.16	4.49	3.52	4.18	5.12	4.04	3.52	3.63	3.66	3.42	4.21	3.94	4.03	4.32	3.70	**0.71**

Appendix Table 3A. *Chemistry data along with GDD (from nearest NEWA station) for the Vidal blanc (VB) and Riesling (RI) wines in the first year.*

	Alcohol (%)	pH	TA (g/L)	Fermentable Sugar (g/L)	Malic Acid (g/L)	VA (g/L)	Free SO2 (mg/L)	Total SO2 (mg/L)	GDD
VB-10-NW	11.4	3.44	6.3	41.1	2.5	0.19	11	69	3029.2
VB-16-NW	12.0	3.41	6.8	36.6	1.9	0.19	29	89	3051.2
VB-02-SE	13.9	3.35	6.9	14.9	2.5	0.50	<5	32	2700.0
VB-03-SE	12.3	3.46	5.4	35.6	1.6	0.29	<5	24	3008.5
VB-09-SE	12.9	3.68	5.8	50.3	2.2	0.33	11	60	3224.2
VB-14-SE	9.8	3.41	8.0	51.2	3.3	0.42	39	173	3224.2
VB-18-SE	11.4	3.39	7.6	0	3.0	0.24	51	150	3982.0
VB-04-SC	12.0	3.42	6.8	32.3	2.6	0.29	17	140	3449.5
VB-06-SC	12.4	3.25	7.5	6.3	2.3	0.40	12	59	3880.0
VB-07-SC	12.2	3.35	6.4	3.5	2.1	0.30	45	94	3995.0
VB-25-NY	12.0	3.40	7.3	19.7	2.5	0.36	17	66	2853.7
VB-26-VA	13.1	3.27	7.3	20.4	1.9	0.18	11	65	3577 .0
RI-01-NW	11.7	3.07	6.4	5.8	2.5	0.50	22	100	3029.2
RI-08-NW	9.6	3.37	6.4	43.6	2.1	0.39	14	144	3102.7
RI-15-NW	12.8	3.33	6.2	32.7	1.5	0.32	<5	63	2794.7
RI-19-NW	9.7	3.33	6.5	30.7	2.2	0.37	21	205	3102.7
RI-11-SE	11.8	3.33	6.6	6.9	2.2	0.39	17	26	3224.2
RI-13-SE	12.6	3.08	7.4	15.0	2.1	0.45	20	60	3224.2
RI-17-SE	13.0	3.19	6.9	23.2	1.6	0.27	65	211	3747.5
RI-23-SE	12.3	2.95	7.1	0	0	0.40	<5	<5	4155.0
RI-12-SC	11.6	3.24	6.3	1.2	1.6	0.35	25	136	328.3
RI-22-SC	12.3	3.08	7.8	33.5	1.8	0.26	11	67	3604.2
RI-05-NC	12.1	3.21	6.4	4.2	1.6	0.38	16	133	3298.0
RI-20-NE	10.9	2.93	8.1	38.5	1.0	0.21	10	61	3279.5
RI-21-NE	11.8	3.36	5.7	15.1	1.2	0.21	14	44	3279.5
RI-24-NY	11.4	3.10	7.9	21.3	1.4	0.40	8	94	2744.3
RI-27-WA	12.2	3.23	7.0	18.4	2.0	0.16	11	60	1069.0

Appendix Table 3B. *Chemistry data along with GDD (from nearest NEWA station) for the Vidal blanc (VB) and Riesling (RI) wines in the second year.*

	Alcohol (%)	pH	TA (g/L)	Fermentable Sugar (g/L)	Malic Acid (g/L)	VA (g/L)	Free SO2 (mg/L)	Total SO2 (mg/L)	GDD
VB_11_NW	11.3	3.27	5.6	39.7	1.31	0.21	27	89	3010.8
VB_13_NW	11.2	3.43	6.0	33.4	1.82	0.29	4	101	3010.8
VB_14_NW	11.0	3.34	5.6	22.3	1.33	0.25	7	43	3010.8
VB_15_NW	10.5	3.40	6.8	31.1	2.21	0.34	37	171	2931.6
VB_01_SE	12.0	3.46	8.0	6.2	3.51	0.22	20	168	3953.5
VB_02_SE	12.1	3.78	5.3	7.4	0.86	0.40	40	115	3239.2
VB_08_SE	11.4	3.34	5.9	24.3	0	0.42	16	58	3239.2
VB_09_SE	11.6	3.50	5.8	31.0	1.97	0.32	8	49	2952.5
VB_10_SE	10.9	3.42	6.5	47.4	2.27	0.19	24	86	3611.0
VB_21_SE	11.5	3.80	5.7	34.1	1.64	0.30	45	144	3239.2
VB_04_SC	10.8	3.31	7.2	23.8	2.65	0.24	9	69	3806.0
VB_05_SC	13.6	3.27	6.0	17.0	1.22	0.28	41	113	3995.0
VB_06_SC	10.7	3.38	5.4	31.0	1.42	0.21	6	61	3476.7
VB_12_SC	11.8	3.68	6.5	11.4	2.74	0.28	14	56	3806.0
VB_16_SC	12.8	3.40	7.5	5.8	2.43	0.40	16	98	3806.0
VB_17_SC	13.0	3.19	6.2	6.7	0.79	0.30	12	60	3995.0
VB_03_SW	10.9	3.37	7.0	19.2	2.43	0.35	21	204	2701.5
VB_07_SW	11.0	3.30	7.5	12.0	2.20	0.29	30	137	3594.5
VB_18_NY	11.2	3.27	6.5	15.0	1.99	0.23	21	50	3059.4
VB_19_VA	12.0	3.11	7.4	19.6	1.41	0.23	12	68	3337.0
VB_20_NJ	10.9	3.51	6.0	5.6	2.02	0.29	28	128	3665.0
RI_01_NW	11.0	3.34	6.2	26.7	2.16	0.27	30	158	3010.8
RI_02_NW	11.9	3.28	5.8	2.9	1.62	0.27	18	66	3010.8
RI_04_NW	10.6	3.26	6.9	20.1	2.33	0.30	20	151	3010.8
RI_05_NW	10.8	3.18	6.7	7.3	1.59	0.24	31	69	2931.6
RI_16_NW	12.2	3.16	6.4	31.6	1.84	0.19	<5	67	3102.7
RI_19_NW	12.6	3.14	7.0	6.4	1.29	0.43	17	141	3010.8
RI_03_SE	7.6	3.40	7.1	4.8	0	0.46	<5	<10	4084.5
RI_06_SE	11.2	3.59	7.0	7.0	3.70	0.24	32	67	3239.2
RI_07_SE	11.4	3.41	5.8	42.0	0.69	0.41	22	122	3239.2
RI_08_SE	11.9	3.48	6.3	8.6	2.00	0.39	<5	117	3982.0
RI_09_SE	11.5	3.48	5.6	5.2	2.17	0.26	21	86	3224.2
RI_13_SE	11.1	3.56	6.6	8.9	2.62	0.36	31	123	3239.2
RI_18_SE	10.1	3.17	7.8	3.1	2.80	0.31	<5	52	3953.5
RI_20_SE	11.4	3.2	7.2	6.5	1.96	0.26	28	74	3239.2
RI_11_SC	11.1	3.21	6.9	8.6	1.97	0.26	20	82	3261.3
RI_12_SC	13.4	3.29	7.0	15.5	1.86	0.30	42	147	3806.0
RI_15_SC	10.6	3.18	6.9	22.8	1.79	0.25	13	65	3476.7
RI_14_NC	11.1	3.37	5.8	60.8	1.06	0.31	36	89	3261.3
RI_17_NC	11.4	3.36	5.9	21.3	2.19	0.24	<5	33	3261.3
RI_10_NE	10.4	2.96	7.9	30.6	1.66	0.23	26	74	3141.0
RI_21_NY	12.3	3.17	7.4	6.8	2.02	0.32	18	124	2573.2
RI_22_WA	11.7	3.01	7.3	17.4	0.76	0.27	26	94	1135.0

Appendix Table 4A. *Vidal blanc Year 1 PLSR attribute variance explained cumulatively by the first and second components.*

Attributes	Dim. 1	Dim. 2	Cumulative
Apple Aroma	14.0	8.2	22.2
Pear Aroma	19.1	0.0	19.2
Stonefruit Aroma	0.1	20.0	20.1
Oxidized Aroma	5.5	22.0	27.6
Chemical Aroma	6.5	20.8	27.4
Canned Vegetable Aroma	0.2	4.0	4.2
Pear Flavor	46.2	2.0	48.2
Grape Favor	**73.6**	**0.0**	**73.6**
Mixed Fruit Flavor	**75.8**	**1.0**	**76.8**
Citrus Flavor	**77.3**	**4.9**	**82.2**
Honey Flavor	**71.2**	**1.0**	**72.1**
Oxidized Flavor	**59.8**	**13.9**	**73.7**
Chemical Flavor	**28.5**	**49.2**	**77.7**
Canned Veggie Flavor	32.0	4.2	36.1
Sweet Taste	**88.8**	**2.3**	**91.1**
Sour Taste	**87.8**	**0.7**	**88.6**
Bitter Taste	**82.9**	**3.4**	**86.3**
Astringent Mouthfeel	**77.8**	**14.2**	**92.0**
Warm/Hot Mouthfeel	**35.9**	**41.5**	**77.4**

Appendix Table 4B. *Riesling Year 1 PLSR attribute variance explained cumulatively by the first and second components.*

Attributes	Dim. 1	Dim. 2	Cumulative
Apple Aroma	15.6	2.5	18.1
Grape Aroma	31.6	11.2	42.8
Stonefruit Aroma	6.4	2.9	9.3
Citrus Aroma	3.9	1.6	5.5
Honey Aroma	41.9	1.1	43.0
Oxidized Aroma	17.4	28.6	46.0
Ethanol Aroma	23.0	3.2	26.2
Chemical Aroma	39.8	3.4	43.1
Canned Vegetable Aroma	3.8	3.1	6.9
Woody Aroma	4.3	17.2	21.5
Grape Flavor	78.4	0.5	78.9
Citrus Flavor	**62.4**	**6.9**	**69.4**
Honey Flavor	**59.6**	**4.5**	**64.1**
Oxidized Flavor	**60.4**	**0.2**	**60.5**
Chemical Flavor	**77.4**	**0.1**	**77.5**
Canned Vegetable Flavor	28.8	0.1	28.9
Sweet Taste	**78.2**	**16.4**	**94.6**
Sour Taste	**85.9**	**2.4**	**88.4**
Bitter Taste	**83.2**	**6.0**	**89.2**
Astringent Mouthfeel	**80.7**	**6.7**	**87.4**
Warm/Hot Mouthfeel	**74.1**	**0.0**	**74.1**

Appendix Table 4C. *Vidal blanc Year 2 PLSR attribute variance explained cumulatively by the first and second principle components.*

Attributes	Dim. 1	Dim. 2	Cumulative
Citrus Aroma	0.9	2.7	3.6
Stonefruit Aroma	1.2	26.8	27.9
Apple Aroma	5.2	29.4	34.6
Mixed Fruit Aroma	1.3	18.7	20.0
Canned Vegetable Aroma	8.2	12.6	20.8
Soil/Mushroom Aroma	5.6	7.9	13.6
Chemical Aroma	1.2	22.4	23.6
Honey Aroma	10.0	5.7	15.7
Floral Aroma	0.6	18.1	18.7
Grape Aroma	16.9	13.9	30.7
Anise Aroma	6.5	1.0	7.6
Brothy Aroma	6.6	4.7	11.2
Sulfur Aroma	7.6	3.1	10.8
Citrus Flavor	**63.2**	**3.0**	**66.2**
Stonefruit Flavor	28.3	4.3	32.6
Pear Flavor	73.0	0.2	73.2
Apple Flavor	22.6	17.4	39.9
Mixed Fruit Flavor	**64.5**	**0.0**	**64.5**
Canned Vegetable Flavor	23.8	11.1	35.0
Soil Mushroom Flavor	14.6	2.7	17.2
Wood Flavor	7.4	7.9	15.3
Chemical Flavor	**39.2**	**22.6**	**61.8**
Honey Flavor	**68.8**	**0.8**	**69.6**
Floral Flavor	0.2	21.0	21.2
Ethanol Flavor	52.1	0.0	52.1
Oxidized Flavor	4.8	0.4	5.3
Grape Flavor	**60.3**	**0.8**	**61.2**
Anise Flavor	0.0	3.7	3.7
Brothy Flavor	45.0	0.5	45.5
Sulfur Flavor	24.4	7.6	32.0
Sweet Taste	**71.0**	**1.5**	**72.5**
Sour Taste	**73.7**	**0.9**	**74.5**
Bitter Taste	**73.0**	**0.0**	**73.0**
Viscous Mouthfeel	10.2	22.7	32.9
Astringent Mouthfeel	**69.4**	**7.6**	**77.0**
Warm/Hot Mouthfeel	**65.6**	**0.0**	**65.6**

Appendix Table 4D. *Riesling Year 2 PLSR attribute variance explained cumulatively by the first and second principle components.*

Attributes	Dim. 1	Dim. 2	Cumulative
Citrus Aroma	0.1	6.4	6.5
Pear Aroma	2.0	5.8	7.7
Apple Aroma	1.4	0.8	2.2
Canned Vegetable Aroma	8.8	21.2	30.0
Soil/Mushroom Aroma	11.7	8.7	20.4
Woody Aroma	0.3	0.0	0.3
Floral Aroma	25.3	2.8	28.1
Ethanol Aroma	2.1	31.3	33.5
Oxidized Aroma	17.5	28.1	45.6
Grape Aroma	2.2	8.7	11.0
Anise Aroma	3.9	20.2	24.2
Brothy Aroma	9.4	5.6	15.0
Bready/Yeasty Aroma	5.6	40.3	45.9
Sulfur Aroma	2.3	1.4	3.7
Citrus Flavor	**38.5**	**27.6**	**66.1**
Stonefruit Flavor	55.3	3.7	59.1
Pear Flavor	30.6	0.0	30.6
Apple Flavor	28.2	25.8	54.0
Mixed Fruit Flavor	**62.2**	**14.4**	**76.6**
Canned Vegetable Flavor	33.1	20.9	53.9
Soil/Mushroom Flavor	27.8	12.9	40.8
Chemical Flavor	27.0	4.7	31.8
Honey Favor	**71.6**	**9.3**	**80.9**
Ethanol Flavor	0.9	47.9	48.8
Oxidized Flavor	39.9	14.0	53.9
Grape Flavor	48.4	0.4	48.8
Anise Flavor	0.0	55.9	55.9
Brothy Flavor	37.7	0.6	38.3
Bready/Yeasty Flavor	33.6	13.0	46.6
Sulfur Flavor	24.0	3.8	27.8
Sweet Taste	**76.0**	**4.8**	**80.8**
Sour Taste	**79.0**	**2.0**	**81.0**
Bitter Taste	**58.3**	**5.4**	**63.6**
Viscous Mouthfeel	27.0	30.0	57.0
Astringent Mouthfeel	**41.0**	**37.1**	**78.1**
Warm/Hot Mouthfeel	2.4	46.2	48.6

Chapter 3 Supplementary Tables

Appendix Table 5. *Number of times codes were used by wine professionals to describe wines separated by year and variety.*

	Frequency			
Code	**RI Year 1**	**VB Year 1**	**RI Year 2**	**VB Year 2**
Acid	27	22	30	22
Aftertaste	--	20	--	--
Appearance	--	--	24	--
Aroma	62	22	25	71
Bad	--	--	31	31
Dry	36	49	21	23
Faulty/Off	70	27	67	64
Flavor	20	--	--	25
Fruity	35	27	27	36
Good	26	--	--	--
Low Intensity	47	37	--	25
Sweet	23	53	--	44
Sweet/Med	--	40	--	--

Appendix Table 6. *Words used by winemakers that were then coded by independent coders. Note that some words were given multiple codes.*

Codes	Winemaker Words
Acid	Sour; Sour acids; Acidic; Acidity; Tart; Citric
Aftertaste	Aftertaste
Appearance	Color; Golden
Aroma	Smell(s); Nose(s); Aroma; Aromatic(s); Odor; Malodorous
Bad	Awful; Unpleasant; Smells; Not commercially viable; Not commercially acceptable; Rough nose and taste; Beyond tolerance; Didn't care for; Hard to drink; Yuk
Dry	Dry; Drier; Dryish
Faulty/Off	Not commercially viable; Flawed; Fault(s); Faulty; Faulted; Defected; Brett; Acetaldehyde; Off; Corked; Reduction; Skunky; Plastic; Near Vinegar; Oxidation; Solvent; Chemical; Rubber; Malodorous; Something odd going on
Flavor	Taste(s); Flavor(s)
Fruity	Fruit; Fruity; Apple; Green Apple; Citrus; Citric; Pear; Melon; Raisins; Stonefruit
Good	Pleasant; Nice wine; Really nice; Favorite(s); Great; Winner winner chicken dinner; Good; What I would drink; Nice all over
Low Intensity	Little; Watery; Mellow; Less taste; Watered down; Light; Lighter; Less Intense; Flat; Not as much aroma; Nondescript; Lean; Weak; Mild; Milder; Slight bland; No substantial flavor
Sweet	Sweet; Sweetness
Sweet/Med	Medium sweet; Some RS; Semi-sweet; Not too sweet