PROGRESS REPORT TO:

<u>Pennsylvania Wine Marketing and Research Board</u>
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Do Pennsylvanian Riesling and Vidal Blanc Wines Differ in their Sensory Properties Across Different Regions?

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Project Overview
The regional character of wines is one of the most compelling selling arguments to wine consumers, as it provides a connection between something we consume to the place it was grown and produced. Based on our first-year pilot study, we propose to extend and validate our results on regional differences in Riesling and Vidal blanc wines across Pennsylvania, to provide scientific evidence of a "sense of place" for PA Riesling and Vidal blanc wines. This information could be utilized in establishing regional branding for the local wine industry and as a measure to distinguish PA from wines from other states in the North East of the U.S.

Objectives:
1) Evaluate whether regional sensory fingerprints exist among Pennsylvanian Riesling and Vidal blanc wines, using a trained descriptive analysis panel.
2) Evaluate whether regional sensory fingerprints exist among Pennsylvanian Riesling and Vidal blanc wines, using a group of Pennsylvanian wine professionals.
3) Provide the Pennsylvanian wine industry with scientific data about sensory regionality of two white cultivars.

Status of Activities
A total of 43 commercial Riesling and Vidal blanc wines were purchased directly at the producing winery, and analyzed for (i) basic wine chemistry measurements (pH, TA, ethanol, free and total SO_2, residual sugar; (ii) sensory fingerprints by a trained descriptive analysis (DA) panel; and (iii) sensory similarities by wine professionals in a free sorting (FS) exercise.
All research activities are completed, and results have been analyzed and two manuscript have been completed. One of them (see Appendix A) has been submitted to the *American Journal of Enology & Viticulture* in December. The second manuscript has been completed and will be submitted for peer-review soon (see Appendix B). Results have been presented at the Australian Technical Wine Conference in July 2019, the Pangborn symposium in August 2019, and will be also presented at the PA WMRB symposium in May.

Topline Findings
1. Basic chemical analysis showed large differences especially in free and total SO_2 levels, with free sulfur-dioxide levels ranging from less than 5 mg/L (detection limit) to 65 mg/L.
2. Both Riesling and Vidal blanc wines showed significant sensory differences between the six winemaking regions in Pennsylvania. Consistent regional profiles were found to be based most likely

on winemaker choice in back-sweetening: the northwest region produced consistently sweeter wines than all other regions, whereas a prevalence for dry Rieslings was found for the southeast region.

3. Results from 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
4. This study provides further support of sensory regionality among Pennsylvanian white wines.

APPENDIX A

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

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Short version of title (under 40 characters) Regionality of Pennsylvanian white wines

Abstract

This research aimed to scientifically explore the colloquial existence of differences between wine regions in Pennsylvanian white wines, specifically *Vitis vinifera* cv. Riesling and the interspecific hybrid Vidal blanc (*V. vinifera* cv. Ugni blanc × Rayon d'Or). Sixty-one Pennsylvanian and nine non-Pennsylvanian commercial Riesling and Vidal blanc wines were tasted and profiled by a descriptive analysis panel over two years. Basic wine chemical data was also collected for each of the wines. Both Riesling and Vidal blanc wines showed significant sensory differences between the six winemaking regions in Pennsylvania. Consistent regional profiles were found to be based most likely on winemaker choice in back-sweetening: the northwest region produced consistently sweeter wines than all other regions, whereas a prevalence for dry Rieslings was found for the southeast region.

Interpretive Abstract

This research scientifically explores sensory differences in commercial Riesling and Vidal blanc white wines from different wine regions in Pennsylvanian. Sixty-one Pennsylvanian and nine non-Pennsylvanian commercial Riesling and Vidal blanc wines were tasted and profiled by a trained sensory panel over two years, together with basic wine chemical measurements. Both Riesling and Vidal blanc wines showed significant sensory differences between the six winemaking regions in Pennsylvania. This study provides further 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 wines from the southeast of Pennsylvania are characterized by lower sweetness levels, particularly for Rieslings. This research explored how

Pennsylvanian wine regions may be distinguished based on sensory fingerprints.

Key words: Descriptive Analysis; White Wine; Riesling; Vidal blanc; Pennsylvania; Regionality

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 variety.

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., 2011; Tomasino et al., 2013; King et al., 2014). 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 commercial and winemaking was controlled. For white Sauvignon blanc wines from Austria, France, and New Zealand, winemakers from Marlborough, New

Zealand found regional sensory differences in blind tastings, grouping wines by country (Green et al., 2011).

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, Reynolds, & Lesschaeve, 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 fifth 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 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 quality (Charters & Pettigrew, 2007). Riesling grapes are reported to have a very “typical” or grape variety-driven sensory profile (Winton, Ough, & Singleton, 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.

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).

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. For the second year of study, more wineries were included, totaling to 43 (22 Riesling) wines, with five wines outside Pennsylvania (2 Riesling). 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 truly produced in New York, but less than 10 miles over the PA border in Erie. 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. All wines from the first year of assessment were also included in the second DA with the exception of two, which were not produced in the consecutive vintage. Wines were stored in their original bottles and packaging at room temperature until sampled (within 6 months of purchasing).

Basic wine chemistry analyses were conducted by the Cornell Geneva New York State Wine Analytical Laboratory; these 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.

Descriptive Sensory Analysis

For the first year, a descriptive analysis (DA) panel of eight people (seven females, 24-63 years old) was trained on attributes found in the wines through nine hours of training. The panel developed a list of 14 aroma, 13 flavor, three taste, and two mouthfeel attributes (**Table 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 Penn State 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 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 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 *anis*e 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.

<<Insert Table 1 Here>>

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.).

Data Analysis

DA results were extracted from Compusense and analyzed in R Studio (version 3.4.3, Boston, MA, USA). The SensMixed package (Kuznetsova, Brockhoff, & Christensen, 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 & 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 & Wehrens, 2007).

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. 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 1**). The southwest part of Pennsylvania (SW) does not grow many grapes, thus, the only wines from that region that qualified for this research were Vidal blanc wines analyzed in the second year.

<< insert Figure 1 here >>

Results

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 LSMeans post-hoc comparison results is provided in **Suppl. Tables 1A-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**). For Vidal blanc wines, year one 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 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 blancs 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.

<<Insert Table 2 and 3 Here>>

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

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 2-3**).

Conversely, wines from the southwest (SW) 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 SW 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 2-3**).

For the *bitter* and *sour* taste attributes, Vidal blanc wines from the SW did not show the same trend as the Riesling wines from the SW, 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 most *sour* and least *sweet*; however, no other sensory attributes were found to be consistently higher or lower, leading to less defined regional sensory profiles (**Tables 2-3**).

Looking at the PCA biplots (**Figure 1**) 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 1**), it seems that GDDs are negatively associated to fruity aromas and flavors such as *mixed fruit*, *stonefruit*, 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.

<<Insert Figure 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 SO_2 content, residual sugar (RS), malic acid, and growing degree days (GDD). Chemical measurements of the wines are summarized in **Supplementary Table 2A-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 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 3B**) and second year Riesling (RI) (**Figure 3C**) wines, the second dimension can be mainly attributed to alcohol percentage. In the first year VB wines (**Figure 3B**), the *warm/hot* mouthfeel and *chemical* flavor attributes are highly correlated to alcohol along the second dimension (**Supp. Table 3A**). 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 (**Supp. Table 3D**), closely associated with GDD and VA.

For the first year RI wines (**Figure 3A**), 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 3D**), separation along the second dimension was driven by free and total SO_2 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 **(Supp. Table 3C).**

<<Insert Figure 3>>

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 wines, particularly Rieslings, 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, has a dense community of grape-growers and winemakers, as well as grape research stations run by both Penn State and Cornell universities. 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. 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 differenctiate 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".

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. Climate is not only modulated by location, but also by elevation, bodies of water, and many other factors. 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, Sylvan, & Arrhenius, 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, Sacks, & Jeffery, 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, Appleby, & Menke, 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.

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.

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Table and Figure Titles

Table 1. Descriptors and corresponding references used by the Descriptive Analysis (DA) panels in both years.

Table 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 ($p < 0.05$).

Table 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 ($p < 0.05$).

Figure 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.

Figure 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.

Figure 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.

Supplementary Table Titles

Supplementary Table 1A. Means and LSD values for all significant attributes in the DA of Vidal blanc wines from the first year of research.

Supplementary Table 1B. Means and LSD values for all significant attributes in the DA of Riesling wines from the first year of research.

Supplementary Table 1C. Means and LSD values for all significant attributes in the DA of Vidal blanc wines from the second year of research.

Supplementary Table 1D. Means and LSD values for all significant attributes in the DA of Riesling wines from the second year of research.

Supplementary Table 2A. Chemistry data along with GDD (from nearest NEWA station) for the Vidal blanc (VB) and Riesling (RI) wines in the first year.

Supplementary Table 2B. Chemistry data along with GDD (from nearest NEWA station) for the Vidal blanc (VB) and Riesling (RI) wines in the second year.

Supplementary Table 3A. Vidal blanc Year 1 PLSR attribute variance explained cumulatively by the first and second components.

Supplementary Table 3B. Riesling Year 1 PLSR attribute variance explained cumulatively by the first and second components.

Supplementary Table 3C. Vidal blanc Year 2 PLSR attribute variance explained cumulatively by the first and second principle components.

Supplementary Table 3D. Riesling Year 2 PLSR attribute variance explained cumulatively by the first and second principle components.

Table 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.

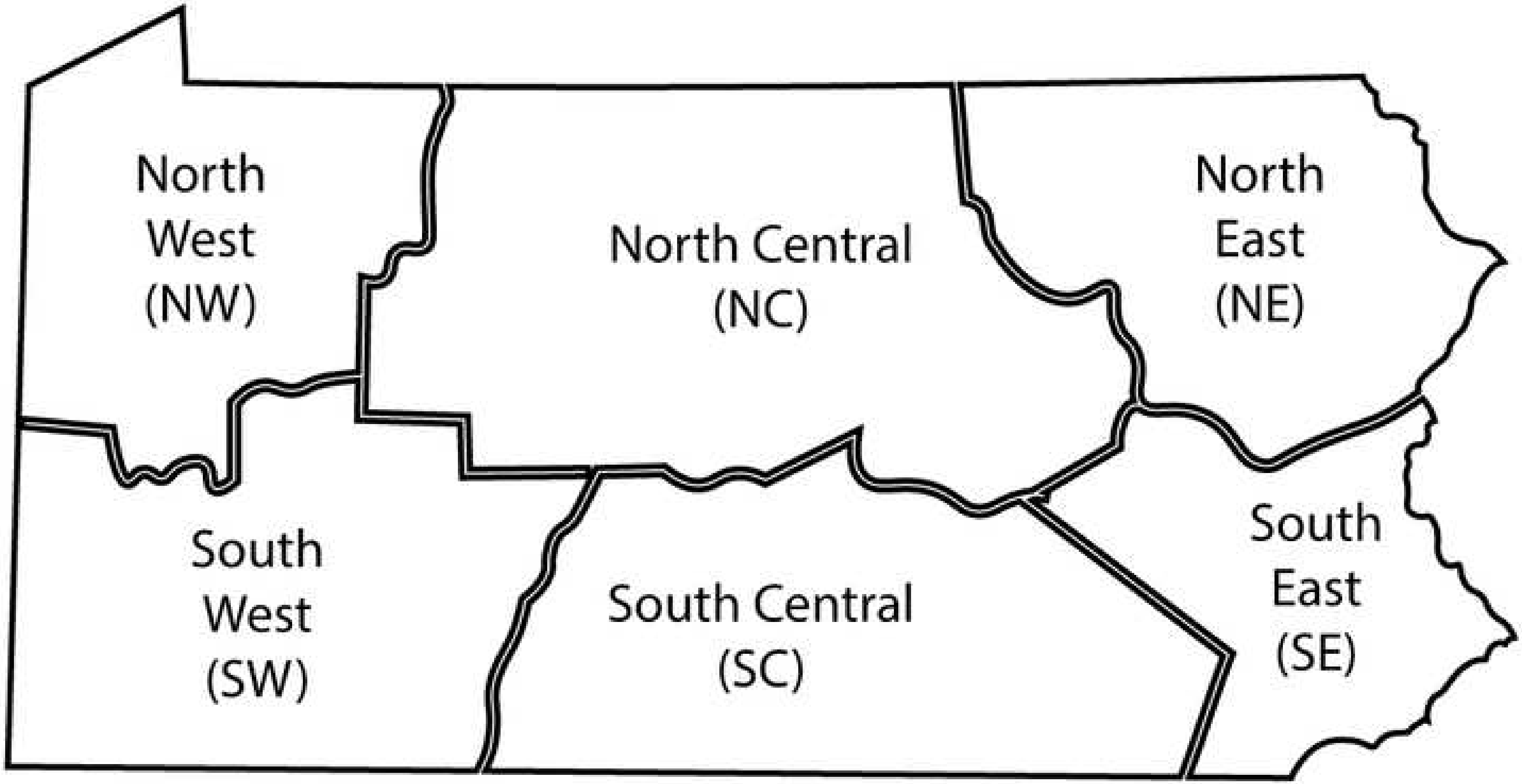
Table 2. Table of the significant differences between Pennsylvania regions for Riesling wines. Values that share the same letter designation within column and year are not significantly different according to Tukey's post-hoc comparison ($p < 0.05$).

	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	

Table 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 b	1.80 b	1.18 a	2.09 ab	1.57 a

Figure 1



North
West
(NW)
North Central
(NC)
North
East
(NE)
South
West
(SW)
South Central
(SC)
South
East
(SE)

Figure 2

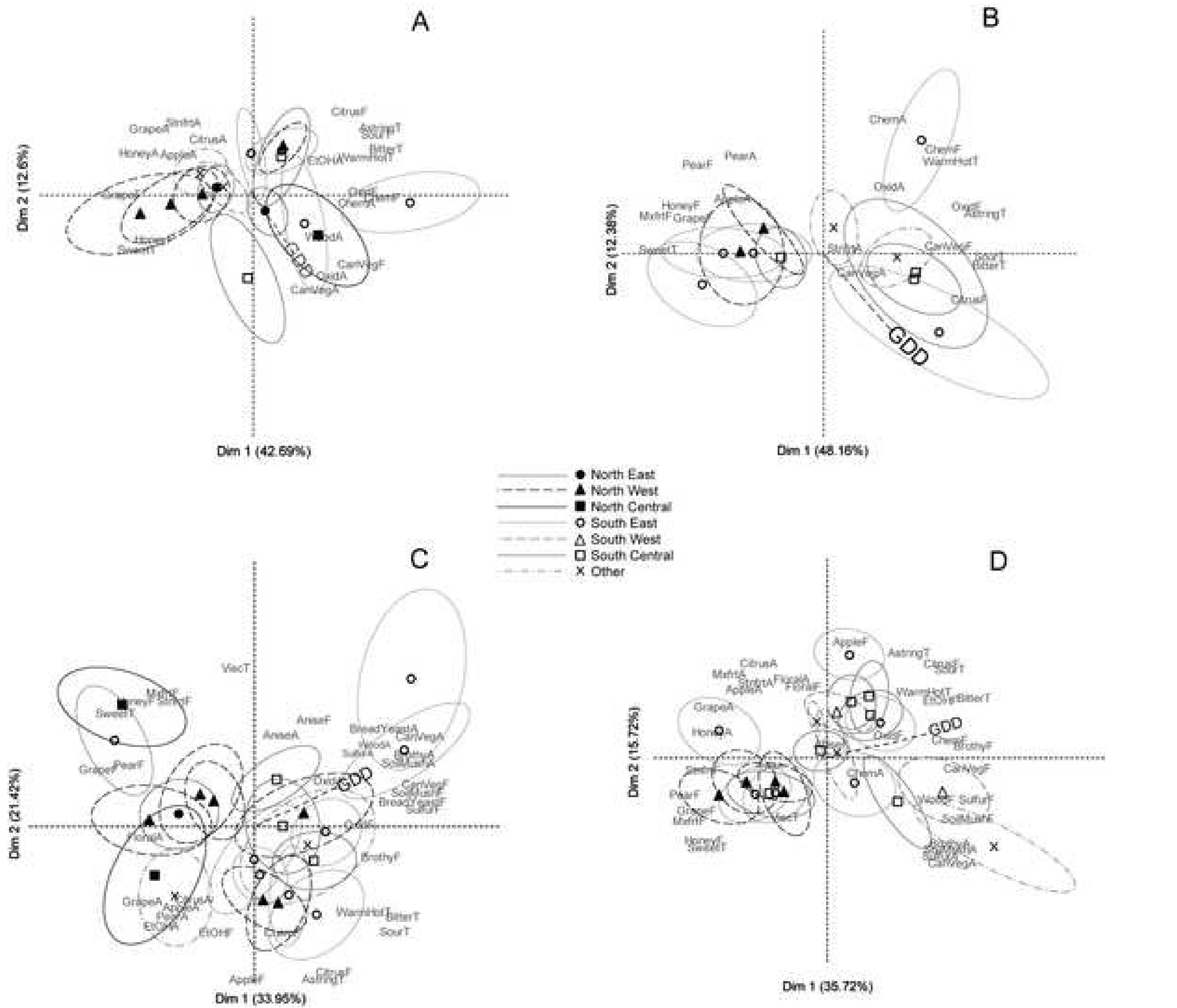
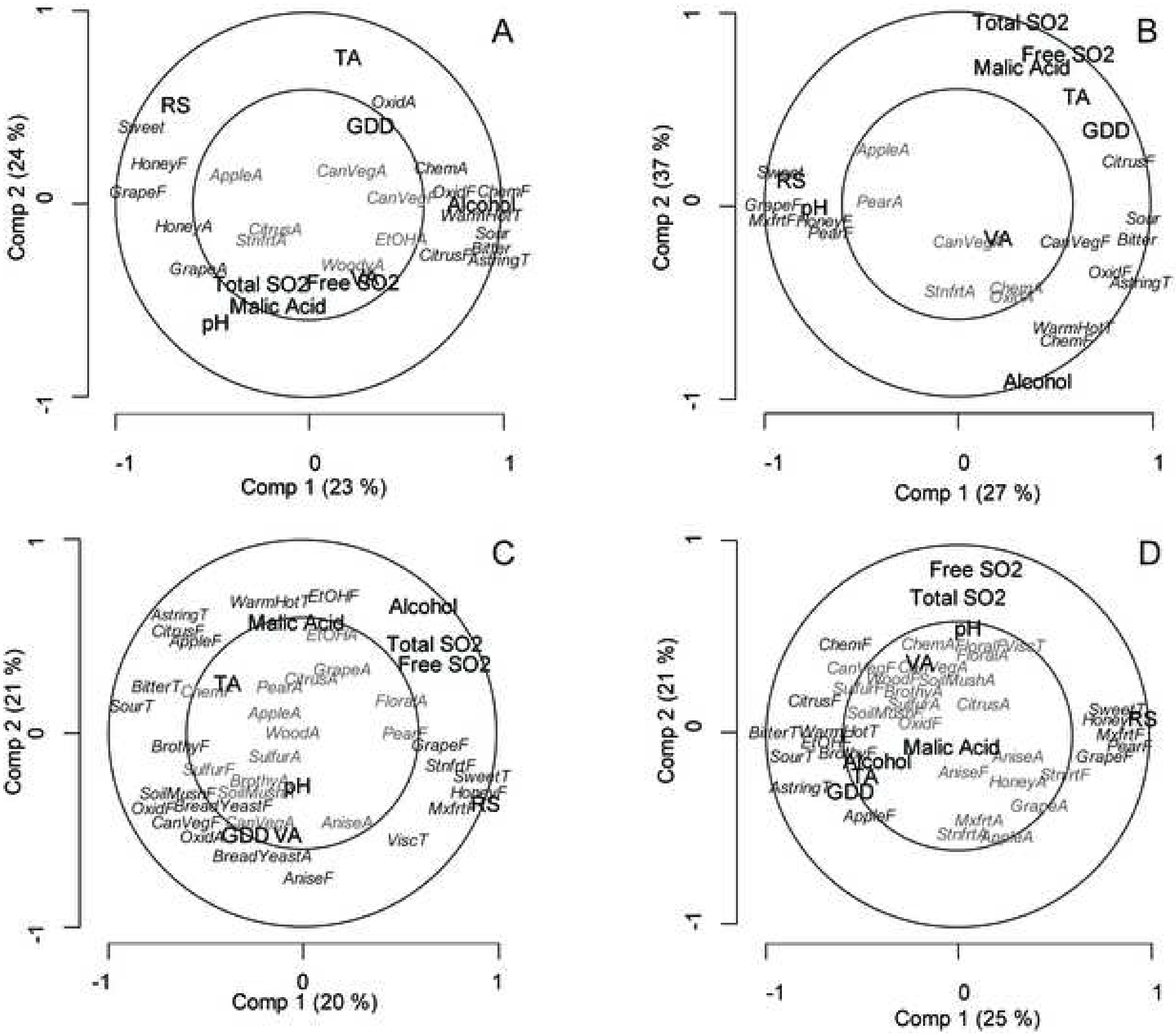

A
B
C
D
Dim 1 (42.69%)
Dim 2 (12.6%)
Dim 1 (48.16%)
Dim 2 (12.38%)
Dim 1 (33.95%)
Dim 2 (21.42%)
Dim 1 (35.72%)
Dim 2 (15.72%)
GDD
North East
North West
North Central
South East
South West
South Central
Other

Figure 3



A
TA
RS
Sweet
OxidA
GDD
HoneyF
AppleA
CanVegA
ChemA
GrapeF
Alcohol
HoneyA
EtOHA
GrapeA
Total SO2
Free SO2
Malic Acid
pH
Comp 2 (24 %)
Comp 1 (23 %)
B
Total SO2
Free SO2
Malic Acid
TA
GDD
AppleA
CitrusF
RS
PearA
pH
VA
CanVegF
Bitter
AstringT
StnfrtA
Alcohol
Comp 2 (37 %)
Comp 1 (27 %)
C
WarmHotT
EtOHF
Alcohol
AstringT
Malic Acid
Total SO2
Free SO2
TA
BitterT
SourT
GrapeA
FloralA
AppleA
WoodA
PearF
GrapeF
BrothyF
SulfurA
pH
RS
GDD VA
BreadYeastA
AniseF
ViscT
Comp 2 (21 %)
Comp 1 (20 %)
D
Free SO2
Total SO2
pH
ChemF
VA
CitrusF
CitrusA
BitterT
Malic Acid
RS
Alcohol
TA
GDD
AstringT
AppleF
GrapeA
Comp 2 (21 %)
Comp 1 (25 %)

Supplementary Table 1A. 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**

Supplementary Table 1B. 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**

Supplementary Table 1C. 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**
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**

Supplementary Table 1D. 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**
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**

Supplementary Table 2A. 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

Supplementary Table 2B. 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

Supplementary Table 3A. 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**

Supplementary Table 3B. 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**

Supplementary Table 3C. 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**

Supplementary Table 3D. 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

APPENDIX B

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

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 regulate 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, etc.) can group wines by general regional characteristics, as shown for New Zealand, French, and Austrian Sauvignon blanc and New Zealand Pinot noir wines (Green et al. 2011, 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 to date in the wine and beer industry, 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 to test 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).

Methods

Samples

Wine samples assessed in two years were collected from Pennsylvania wineries directly. For the first year, 13 Riesling wines and 10 Vidal blanc wines 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).

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.

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

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 blind duplicates (18 wines total) or the full set of Vidal blanc wines with 3 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.

Year 2

A free sorting task was conducted with 24 wine professionals (6 female) who came to Penn State at University Park, PA for an extension 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. 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 their tasting habits, 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 IRB overview based on exempt category 6 (protocol #8551).

Data Analysis

All analysis was 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).

Results

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. The range of age and time in the industry was wide, with ages ranging from 21-24 (3) to over 65 (9). Time in the industry also varied, with some having less than one year in industry (3), and others being in industry over 20 years (9). Wine professionals also ranged in region, with all six Pennsylvanian wine regions being represented, though the North West (19) and South Central (14) being the most represented (the Erie, PA and Breinigsville, PA workshops were heavily attended by professionals of these regions respectively).

Descriptor words

Descriptors for each group provided by wine professionals were pre-processed by correcting spelling errors and separating each code 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.

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 “lowintensity” 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 analysis is given in the appendix (Appendix Table 1).

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 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 1A-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 1A-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 2 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 1A), 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 1B), 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 positioned very close together in this plot, towards the “dry” term. 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 1C), 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 1D), 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 group very closely in all but the second year Vidal blanc wines, and trend towards the dry regions. There does not seem to be a trend with the non-Pennsylvanian data. In the one year where more than one north central wine was included (year 2 RI), 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 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 did not have the word “sweet”), 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 the result of this group of wine professionals – Pennsylvanian wine professionals may have had starts in other industries, or do not have the resources for training, and thus rely on different vocabularies than wine professionals in more developed and established wine growing areas. 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). Therefore, wine professionals in PA may have a different vocabulary than those in more well-known regions.

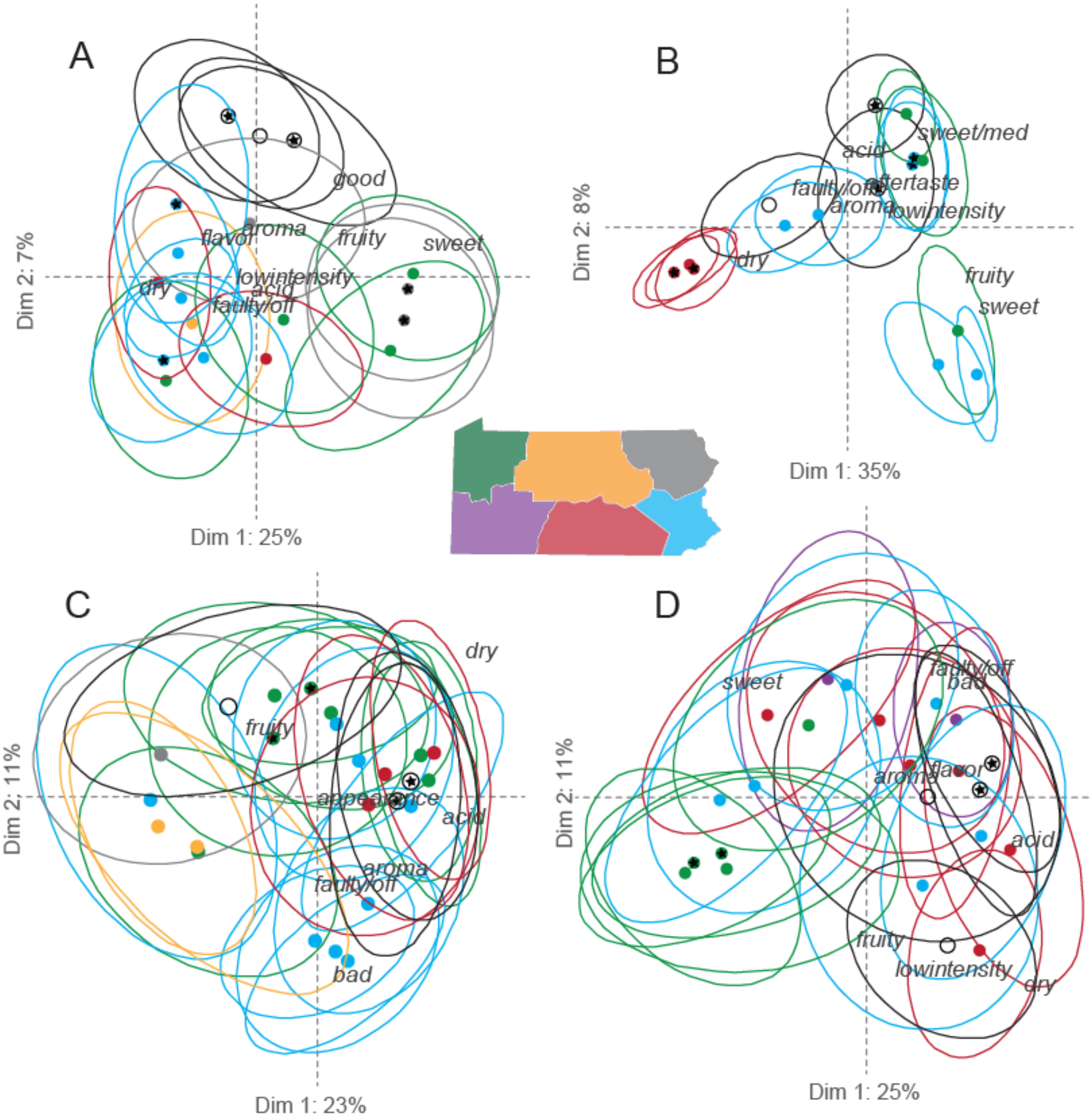


Figure 1 A-D. *Distatis plots of sorted wines separated by variety and year Year 1 Riesling (A), Year 1 Vidal blanc (B), Year 2 Riesling (C) and Year 2 Vidal blanc (D). Regions are colored as shown by the map of Pennsylvania. Stars indicate blind duplicates. Codes projected were used 20 or more times.*

Discussion

Comparing the free sorting maps (Figure 1) to the descriptive analysis results 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 wine professionals in attendance, 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 be more familiar with wines other than their own due to accessibility of training and resources within the state. 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 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 "not sweet". 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. It is also interesting to note that the language used by wine professionals referred to characteristics of wine commonly attributed to winemaking practices – such as amount of residual sugar and faults – instead of more descriptive characteristics describing aroma and flavor, which can be more attributable to the grapes themselves.

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, Lelievre 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.

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.

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Appendix

Table 2. Number of times codes were used by wine professionals to describe wines separated by year and variety.

Code	Frequency 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	--	--	--
Lowintensity	47	37	--	25
Sweet	23	53	--	44
Sweet/Med	--	40	--	--

Table 3. Words used by winemakers, 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
Lowintensity	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