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Sensory analysis of Ontario Riesling wines from various water status zones

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Abstract

Aims: Determinants of the terroir effect in Riesling were sought by choosing vine water status as a major factor. It was hypothesized that consistent water status zones could be identified within vineyards, and, differences in wine sensory attributes could be related to vine water status.

Methods and results: To test our hypothesis, 10 Riesling vineyards representative of each Ontario Vintners Quality Alliance (VQA) sub-appellation were selected. Vineyards were delineated using global positioning systems and 75 to 80 sentinel vines were geo-referenced within a sampling grid for data collection. During 2005 to 2007, vine water status measurements [leaf water potential (ψ)] were collected bi-weekly from a subset of these sentinel vines. Vines were categorized into "low" and "high" leaf ψ zones within each vineyard through use of geospatial maps and replicate wines were made from each zone. Wines from similar leaf ψ zones had comparable sensory properties ascertained through sorting tasks and multidimensional scaling (2005, 2006). Descriptive analysis further indicated that water status affected wine sensory profiles, and attributes differed for wines from discrete leaf ψ zones. Multivariate analyses associated specific sensory attributes with wines of different leaf ψ zones. Several attributes differed between leaf ψ zones within multiple vineyard sites despite different growing seasons. Wines produced from vines with leaf ψ > -1.0 MPa had highest vegetal aromas whereas those with leaf ψ < -1.3 MPa were highest in honey, petrol and tropical fruit flavors. Vines under mild water deficit had highest honey, mineral, and petrol and lowest vegetal aromas.

Conclusion: Results indicate that water status has a profound impact on sensory characteristics of Riesling wines and that there may be a quality threshold for optimum water status.

Significance and impact of the study: These data suggest that vine water status has a substantial impact on the sensory properties of Riesling wines. Variability of leaf ψ within vineyards can lead to wines that differ in their sensory profiles. These findings were consistent among vineyards across the Niagara Peninsula. These strong relationships between leaf ψ and sensory attributes of Riesling suggest that vine water status is a major basis for the terroir effect.

Key words: Vine water status, multivariate statistics, sensory analysis, terroir, precision viticulture

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Introduction

Terroir-related studies have been performed with focus on single variables such as soil (Seguin, 1975) and climate (Tonietto and Carbonneau, 2004). Climate has been shown to be a very important criterion of the terroir effect as it substantially impacts wine character (Jones and Davis, 2000). Soil, however, has traditionally been associated as the main constituent of terroir. While several have looked at characteristics of soils, including chemical constituents, many have indicated that the soil's physical properties involved in regulation of water supply to the vine are the most critical with respect to the terroir effect. In Bordeaux, soil texture and rooting depth were most important, and the best soils were those that were free draining, and those which avoided water logging in the rooting zone but limited water availability later in the season (Seguin, 1970). Many soil effects on vine behavior are due to varying water content levels throughout the growing season and their effects on plant water status. Vine water status is the means by which the terroir effect affects a wine's quality and style (Choné *et al.*, 2001; Koundouras *et al.*, 1999; Willwerth *et al.*, 2009). Vine water supply has been noted as a major factor in the terroir effect due to its impact on early budburst potential and potential vine vigor (Morlat *et al.*, 2001). Grapes cultivated under mild water stress can improve berry composition (Matthews and Anderson, 1988; Smart, 1985) and mild water deficits have been shown to be a major factor in the terroir effect (Seguin, 1983; van Leeuwen *et al.*, 2004; 2009).

Leaf water potential (ψ) has been widely accepted as a fundamental measurement of plant water status in grapevines. Leaf ψ represents a simple and reliable method for evaluating the physiological condition of a plant, since cell growth, photosynthesis and crop productivity are strongly influenced by leaf ψ and its components (Repellin *et al.*, 1997). The influence of water supply on grapevine development and physiology has been widely addressed in the literature (Grimes and Williams, 1990; Hardie and Considine, 1976; Matthews and Anderson, 1988). Grapes are commonly grown in areas with low water supply, where many vineyards are not irrigated and vines are subjected to some form of water stress during the summer months. Generally, the water obtained by grapevines depends on the water table and rainfall. The availability of water to grapevines is one of the most important factors of terroir and determining wine quality (Deloire *et al.*, 2005; Seguin, 1986; van Leeuwen and Seguin, 1994). Water deficits in vines have been shown to reduce shoot growth (Smart, 1974) and canopy density (Smart *et al.*, 1990). Fruit composition may be directly affected by leaf ψ via changes in turgor or indirectly via the effects of canopy sink competition (Smart *et al.*, 1990) and light penetration in the cluster zone (Smart, 1985). Vines suffering from water stress may have less shoot growth and therefore have better leaf and fruit exposure to sunlight than vines growing with abundant water supply with over vigorous canopies and poor fruit exposure.

Most research relating to water relations has involved studies with red wine cultivars. This is probably due to the fact that drought stress regularly occurs in the regions of hotter and drier climates where red grapes thrive and are widely planted. In many of these cases, mild water deficits have been shown to be beneficial to red grape and wine quality mainly due to reduced berry size and increased anthocyanin and tannin content (Kennedy *et al.*, 2002; Roby *et al.*, 2004). Vine water status has substantial impact on vegetative performance (Reynolds and Hakimi Rezaei, 2014a,b; Smart, 1974), fruit composition (Hakimi and Reynolds, 2010; Ledderhof *et al.*, 2014; Reynolds and Hakimi Rezaei, 2014c; Reynolds *et al.*, 2007), and aroma compounds in white wine cultivars (Marciniak *et al.*, 2013; Peyrot des Gachons *et al.*, 2005; Reynolds *et al.*, 2005). In terms of white grape composition, studies are limited but as in the case of red grapes mild deficits also seem to improve grape composition (Peyrot des Gachons *et al.*, 2005; van Leeuwen *et al.*, 2004, 2009). Most studies investigating white wine quality have focused on aroma compounds or their precursors. Vine water status had an impact on volatile thiol precursors in Sauvignon blanc grapes, and mild water deficits resulted in higher grape quality whereas severe water deficits limited aroma potential (Peyrot des Gachons *et al.*, 2005).

While potential quality has been analyzed through measuring chemical variables in fruit, there has not been a focus on wine produced from fruit harvested from vines of different water status, nor has attention been placed upon sensory differences in wines made solely of vines of different water status. In terms of white wine production, the authors could not identify any studies performed to date which used descriptive analysis. Through difference testing, red wines of different water status had different sensory characteristics (Matthews *et al.*, 1990). Differences were found in terms of appearance, aroma, flavor, and taste among irrigation treatments. Through use of descriptive analysis, Cabernet sauvignon wines produced from vines of higher water status were determined to have more vegetal and less fruity aromas and flavors than vines with lower water status (Chapman *et al.*, 2005).

The intent of our research was to study the impact of vine water status within vineyard sites through the use of precision viticulture techniques to minimize any climatic effects. Leaf ψ measurements taken throughout the growing season were used in combination with GIS software to designate specific vines into different leaf ψ categories. Wines were then made with fruit harvested from these vines and then chemical and sensory analyses were conducted in order to determine differences of these resultant wines.

Materials and methods

1. Site selection

Ten Riesling vineyard sites were selected throughout the Niagara Peninsula, Ontario, Canada. These sites were non-irrigated, commercial vineyards and the vineyard blocks had heterogeneous soil types. Each site was also representative of each VQA sub-appellation. In each vineyard block, a grid-style sampling pattern was established with a "sentinel vine" at each grid intersection point. These sentinel vines (72 to 80 per vineyard) were flagged for identification to be used for data collection throughout the year. A global positioning system (GPS; GPS900, Leica Geosystems, Scarborough, ON) was used to geo-reference each sentinel vine and to delineate the shape and size of each vineyard block.

2. Geographic information systems (GIS)

The delineated vineyards and data layers were incorporated into a MapInfo Professional 8.0 GIS database with Vertical Mapper 3.1 (Northwood GeoScience, Ottawa, ON). Interpolation maps were generated for all soil and viticulture variables using the inverse distance weighting interpolation to cartographically depict the spatial distribution of each variable within each vineyard.

3. Soil sampling and composition

Soil samples were collected from every fourth sentinel vine (seven to 35 vines per ha) with an auger from within the row, 40 to 50 cm away from the trunk. Soil was taken from a 0 to 45 cm depth and in total ≈ 350 g of a homogenized sample was taken. Depending on the area of each vineyard block, 15 to 20 soil samples were taken. Soil samples were analyzed for pH, organic matter (OM), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), texture (% sand, silt, clay), cation exchange capacity (CEC), and base saturation (BS; as % Ca, Mg, and K) using standard procedures (CSSS, 1993).

4. Soil water content and vine water status

At each vineyard, soil water content (SWC) and vine water status measurements were taken bi-weekly (every 10 to 14 d) from sentinel vines between the end of June and early September (beginning of fruit set to pre-harvest). SWC was measured using a portable time domain reflectometer (TDR) (Spectrum Technologies, Plainfield, IL). Probe readings were taken in root zones of all sentinel vines at a depth of 20 cm. On the same day, midday leaf ψ was determined on a subset of sentinel vines (≈ 18 vines) using a Scholander-type pressure chamber (Soil Moisture Equipment Corp., Goleta, CA). Measurements were taken between 1100 and 1400 under full sun conditions. Leaf ψ readings were taken from healthy, undamaged leaves that were sun-exposed and at a similar position on the shoot for each sentinel vine. A recently fully-expanded leaf was excised from the sentinel vine with a razor blade and immediately placed in a sealable plastic bag. The leaf was placed in the chamber and the pressure was increased slowly until air bubbles/sap exuded from the leaf petiole. At this point the pressure was recorded.

5. Viticultural data collection

For each sentinel vine, data were collected annually at vine dormancy for weight of cane prunings as an estimate of vine vigor ("vine size"). Yield components (yield per vine; clusters per vine; cluster weight; berries per cluster; berry weight) were either measured directly or calculated from measured variables during harvest each season. Fruit was sorted based on treatments and retained for winemaking. Clusters were counted from each sentinel vine and samples of 100 berries were taken for determination of berry weight and standard fruit composition indices [total soluble solids (TSS; Brix); titratable acidity (TA); pH], whereas samples of 250 berries were taken for monoterpene concentration analyses.

6. Berry and must composition

Each 100-berry and 250-berry sample was weighed to determine the mean berry weight. The frozen berry samples were then heated in 250-mL beakers to an internal temperature of 80°C in an Isotemp 228 water bath (Fisher Scientific, Ottawa, ON) to dissolve any precipitated tartaric acid. The heated berry samples were then cooled, juiced in a laboratory juicer (Omega Products Inc., Harrisburg, PA), and ≈ 35-mL

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was clarified using an IEC Centra CL2 Centrifuge (International Equipment Co., Needham Heights, MA) to remove large particles. TSS were measured on the unclarified berry juice samples using a temperature-compensated Abbé bench refractometer (American Optical Corp., Buffalo, NY). The pH was measured using an Accumet pH/ion meter Model AR50 (Fisher Scientific, Ottawa, ON). TA was measured on 5-mL clarified samples using a Man-Tech PC-Titrate autotitrator (Man-Tech Associates Inc., Guelph, ON). Samples were titrated to a pH 8.2 endpoint with 0.1N NaOH solution. Results were expressed as tartaric acid equivalents (g/L). Monoterpenes were analyzed for the 250-berry samples using the method developed by Dimitriadis and Williams (1984) as modified by Reynolds and Wardle (1989). The free volatile terpene (FVT) and potentially-volatile terpene (PVT) concentrations were expressed as mg/kg. Brix, TA, pH and monoterpenes were performed on must samples using methods identical to those for berries.

7. Winemaking

Within each vineyard block, sentinel vines were sorted based upon leaf ψ and identified on GIS-generated maps. Two leaf ψ categories were established as "high" and "low" and wines were made with the fruit from vines with the highest and lowest leaf ψ, respectively. There were three replicates of both categories (two leaf ψ categories treatments x three replicates). These replicates were both winemaking and vineyard replicates. Vines from intermediate leaf ψ zones were placed into a separate treatment to represent the appropriate VQA sub-appellation for that particular vineyard. Winemaking practices were consistent for all treatments and replicates to minimize enological effects.

The grapes from each treatment replicate were transported from the vineyard and immediately crushed and de-stemmed at the CCOVI winery using an electric crusher/destemmer (Model Pillan N1, Enoitalia, San Miniato, Italy) into 20-L food-grade plastic pails. Sulfur dioxide (SO_2; 30 mg/L) and Scottzyme Cinn-Free pectinase (Scott Laboratories; Pickering, ON; 15 µL/L) were added. Crushed grapes were given 2 hr of skin contact at 7°C prior to pressing. The grapes were pressed to a maximum 0.2 MPa using a water bladder press (Model LDC5518, Enoitalia, San Miniato, Italy). Must samples (≈ 250 mL) were taken from each pressing and frozen at -25°C for further analysis for Brix, TA, pH and monoterpenes (q.v. description of analysis). The pressed juice was cold settled at 7°C for 24 hr prior to being racked into 11-L glass carboys, after which 100 mg N/L was added using a diammonium phosphate addition. The juice was brought to room temperature (20°C) and inoculated with *Saccharomyces cerevisiae* strain W15 (Lallemand Inc., Montreal, QB) at a dosage of 250 mg/L following the manufacturer's recommended rehydration procedure. After 12 hr, the carboys were transferred to a temperature controlled fermentation chamber set to 16°C and remained there until the completion of fermentation (to dryness). Wines were then removed, racked into clean carboys, sulfited to 50 mg/L and transferred to -2°C to undergo cold stabilization and lees contact for ≈ 2 months. Wines were then racked after warming to room temperature and 250-mL wine samples were taken and frozen at -25°C for further chemical analysis (TA, pH, monoterpenes and ethanol; q.v. description of analysis). The wines were analyzed for residual (reducing) sugar using the Lane-Eynon method and sucrose was added to the desired level of 15 g/L residual sugar. Potassium sorbate (150 mg/L) and SO_2 (30 mg/L) were added immediately prior to filtering and bottling. Wines were filtered to 0.45 µm and bottled at 20°C. Wines were stored in at 15°C and 70% relative humidity in a controlled cellar at CCOVI for 12 months prior to sensory analyses.

8. Wine composition

Wine TA and pH were determined by methods identical to those used for berries and musts. Ethanol was determined using a gas chromatography-flame ionization detector (Agilent 6890, Mississauga, ON) equipped with a Carbowax (30 m × 0.23 mm × 0.25 µm) column. A 0.5-µL wine sample was injected into the injection port heated to 250 °C. The carrier gas was helium with a column head pressure of 137.9 kPa. The flow rate of helium carrier gas was 1.8 mL/min. The oven temperature was programmed to start at 60 °C, increase to 125 °C at 6 °C/ min, and then increase to 225 °C at 25 °C/min and hold for 1 min. The detector temperature was 250 °C and 2 % 1-butyl alcohol was used as an internal standard. A six-point calibration curve (4, 6, 8, 10, 12, 14% v/v ethanol) was used and these samples were diluted 1:10.

9. Sensory analysis

9.1 Sorting tasks

A group of untrained participants consisting of 16 wine professionals from the Niagara wine industry were selected on the basis of having extensive experience with Riesling wines. Each person sorted the wines into groups based on retro-nasal perceptions. Evaluations were conducted in a controlled environment. Sorting was performed on a per vineyard basis where panelists received the entire set of wines for each vineyard. The presentation of samples was presented according to a Latin Square. Each participant was asked to sort wines into groups based on similar taste characteristics. No criterion was provided to perform this task and the panelists were free to make as many groups of wines as they wanted but could only group a wine once (i.e. a wine could not appear in more than one group). After performing their sorting task, they were asked to provide descriptors on the basis of their decision to designate the wines into their respective grouping(s). Data from the sorting tasks were put into a distance matrix by the frequency that the wines were grouped together. For each assessor, a value of 1 indicated that the wines were grouped together and conversely a value of 0 meant the wines were not grouped together. For each vineyard, these matrices were then converted into similarity/dissimilarity matrices and were analyzed with multidimensional scaling (MDS) through XLSTAT-pro v. 2008.5.1 (Addinsoft; Paris, France). MDS was conducted for each task using Euclidean distance and was depicted in three-dimensional space using XLSTAT-3D plot. In these maps, the proximity between the wines reflects their similarity.

9.2 Descriptive analysis

The sensory panel ran from October 2007 until March 2008. Participants consisted of graduate students, undergraduate students, staff and faculty who were experienced with Riesling wines and sensory methodology. Most judges had previously participated in descriptive analysis studies. In the first year the panel consisted of five males and six females between the ages of 23 and 65 years (mean = 38). In the second year the panel consisted of seven males and three females between the ages of 23 and 54 years, six of whom were on the previous year's panel.

Training consisted of 16 sessions conducted over 24 hr in the first year and 18 hr in second year. In the first session, the panelists were screened for possible anosmias of typical wine aromas. Panelists were also assessed on odor and taste recognition and ranking ability thorough a series of identification and ranking exercises using model solutions. For the initial training sessions, judges generated descriptive terms describing differences perceived between the wines from the study. During the training period, aroma reference standards were given to define the aroma/flavor descriptors and were discussed and modified based on panel consensus. Standards for sweetness, sourness, bitterness, and astringency were also given during training. Panelists rated the intensities of each attribute for every wine and then

Table 1. Aroma/flavor and taste/mouthfeel attributes used in sensory evaluation of Riesling wines, Niagara Peninsula, Ontario, 2005 to 2006.

Attribute	Reference (base wine was a neutral Ontario Riesling wine)
Apple/pear	5 g fresh Bartlett pear and 5 g Granny Smith and Red Delicious apples in 50 mL base wine
Baking spices (aroma only)	5 mL of stock solution [a]
Citrus	Fresh lime juice (20 mL), lemon juice (10 mL), and grapefruit juice (5 mL) in 100 mL base wine
Honey	President's Choice alfalfa honey (10 g in 50 mL base wine)
Mineral/flint	Ground slate (5 g) in 20 mL base wine
Peach	Yoga peach nectar (25 mL) in 100 mL base wine
Petrol	1 drop WD-40™ in 900 mL base wine
Tropical fruit	McCain Tropical fruit juice (10 mL), Rubicon Passion fruit juice (5 mL), and Rubicon Guava juice (5 mL) in 300 mL base wine
Vegetal	10 mL of vegetal stock solution [b] and canned bean brine (5 mL) in 100 mL base wine
Taste/mouthfeel attributes	
Attribute	Reference (in 1000 mL water)
Sweet	10 g sucrose
Sour	1.5 g citric acid
Bitter	0.01 g quinine
Astringent	0.05 g aluminum sulfate

following discussion and panel consensus the most appropriate descriptors to define and discriminate sensory differences in the wines were chosen.

The 17 aroma and flavor attributes that were selected are listed with the composition of the reference standard included (Table 1). The four taste and tactile terms selected are also listed with their reference standard compositions. These references were presented during all formal data collection sessions. Sensory evaluations were conducted using Compusense Five ® version 4.6 software (Guelph, ON, Canada) in individual booths at 18EC in the sensory laboratory at CCOVI. Wines were served in a random order using a Williams Latin Square design (MacFie *et al.*, 1989) and duplicated. Six wines were presented during each session as 30-mL samples contained in coded black glasses covered with plastic Petri dishes. There were forced 3-min breaks between samples with a 30-min break after the third sample. Judges were familiarized with the reference standards at the beginning of each session and the intensity of each aroma, flavor and taste/mouthfeel attribute was scored on an unstructured 15-point intensity scale anchored with 'absent' and 'high'. Mineral water and filtered water were provided for rinsing between samples as well as unsalted crackers. All samples were expectorated following evaluation.

10. Data analysis

Analysis of variance (ANOVA) was performed with judges, wines, and replicates as fixed effects using SENPAQ v. 4.1 statistical packages (Qi Statistic Ltd.; Reading, UK). Least significant differences (LSD) between sample means were used. Principal components analysis (PCA) was performed for the means of all significant sensory attributes based on a covariance matrix using XLSTAT-pro 2008.5.1 (Addinsoft; Paris, France) with MX and PLS modules.

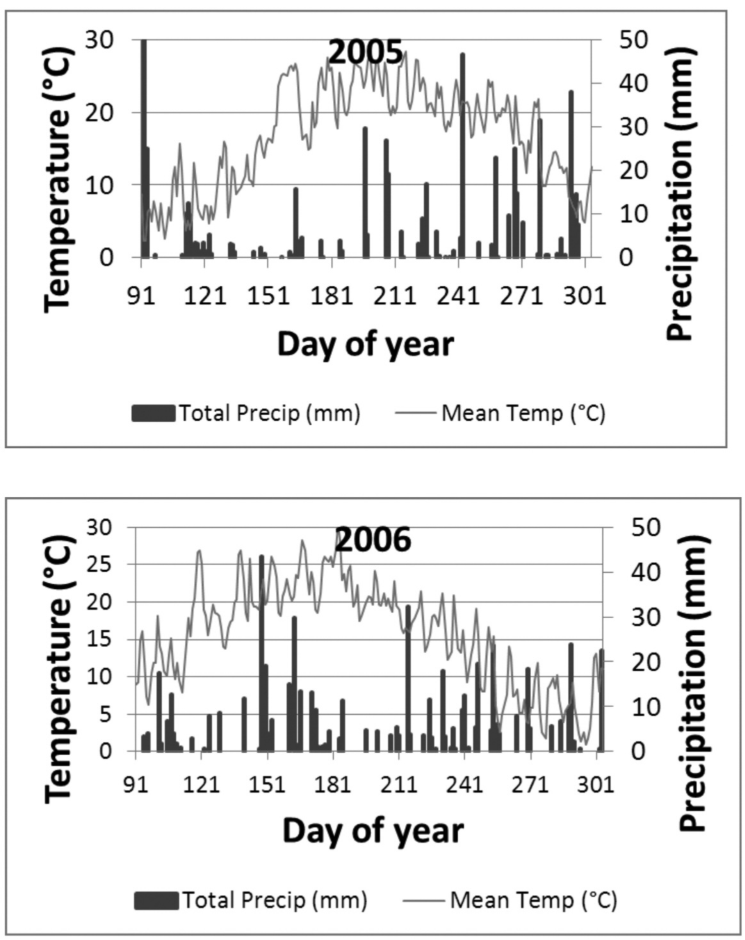

Figure 1. Climate data for the 2005 and 2006 growing seasons. Vineland Station, Ontario.

Results

1. General comments and spatial aspects

The 2005 and 2006 growing seasons were ideal for studying the impact of vine water status. Climate data for the two growing seasons are shown in (Figure 1). The 2005 vintage was a hot and dry growing season with abundant sunshine allowing for an earlier harvest. There were many days throughout June, July and August which exceeded 30°C. From the beginning of May until the middle of August there were few rain events > 10 mm of precipitation. Autumn rainfall events were quite sporadic; however, Riesling harvests occurred prior to many of the heavier rains caused by Hurricane Katrina (Figure 1A). The 2006 growing season was cooler and wetter than the previous vintage. In general, the growing season was warm but there were more rainfall events particularly during the harvest period. There were, however, periods lacking rain. From the beginning of June until the beginning of August there was an extensive period of drought with only one rainfall event > 15 mm. June and July were characterized by many days between 25 and 30 °C (Figure 1B).

Through the use of GPS and GIS technologies, leaf ψ data collected from each vintage were depicted cartographically and analyzed (Figure 2). Consistent leaf ψ zones could be delineated and spatial patterns of vine leaf ψ were temporally stable within all vineyards in the study despite different weather conditions during each growing season. In every vineyard studied, distinct regions were delineated that could be categorized as "high" and "low" leaf ψ. This is consistent with Acevedo-Opazo *et al.* (2008) who found it possible to assess spatial variability of vine water status within vineyards, even those small in size (< 1 ha). In many cases, particularly in the hot and dry 2005 vintage, the "low" leaf ψ regions consisted of vines suffering moderate water stress. In general, there were more sites with higher within-site variability in terms of leaf ψ in 2005.

2. Sensory sorting tasks

The use of sorting tasks is a simple but very reliable method to collect similarity data and have been used in numerous studies involving wine (Parr *et al.*, 2007). One of its main advantages is that sorting tasks are less tedious and time consuming than other methods so information can be obtained about sensory differences among products in an efficient manner (Abdi *et al.*, 2007). Sorting tasks are particularly suitable when there are a large number of samples as was the case in this study. Most importantly results obtained are comparable with those obtained from other sensory descriptive methods such as free profiling (Tang and Heymann, 2002). Similar findings were obtained with descriptive and sorting tasks which is consistent with other research experiments (Preston *et al.*, 2008).

Sorting tasks performed on wines from the 2005 and 2006 vintages indicated that wines of similar leaf ψ had similar sensory properties through sorting tasks and multidimensional scaling. Three dimensions were used as opposed to two dimensional space to reduce Kruskal Stress values to acceptable levels < 0.1. Then, 3-D plots were created to ease interpretation rather than using biplots, which did not capture the necessary space of the data set. For many of the vineyards, the wine treatments were visibly separated into two groups based on leaf ψ (date not shown). Kruskal Stress values were in all cases between 0.05 and 0.10 for all vineyards in both seasons. In some cases one of the treatment replicates was separate from the other treatment replicates. These findings are explainable by the fact that there were not large enough differences in leaf ψ between treatments. The separation of "low" and "high" leaf ψ wines was greater in the warmer and drier 2005 vintage than the cooler, wetter 2006 vintage. The longer period of drought in 2005 resulted in a greater range of leaf ψ values within many of the vineyard blocks as opposed to the 2006 growing season where wetter conditions resulted in less variability within sites.

3. Sensory descriptive analysis

3.1 Analysis of variance

Descriptive analysis further indicated that leaf ψ had an effect on wine sensory profiles and also described these differences in terms of aroma and flavor attributes, and revealed that wines of different leaf ψ zones had distinctive sensory profiles due to differences in the levels of the intensity of aromas and flavors.

2005: Results from ANOVA are in Table 2. Within-site sensory differences of wines ranged from four to nine aroma and flavor attributes with a median of seven. The most common aroma attributes to differ were honey (four sites), mineral/flint (three sites), and vegetal aromas (three sites) followed by petrol, tropical fruit and baking spice. Honey (six sites), apple/pear (five sites), citrus (four sites), and petrol flavors (three sites) were the most common flavor attribute differences followed by tropical fruit. Sour and sweet tastes were different in seven and four vineyards, respectively. Peach aroma and bitter taste were non-factors in 2005 whereas apple/pear aroma,

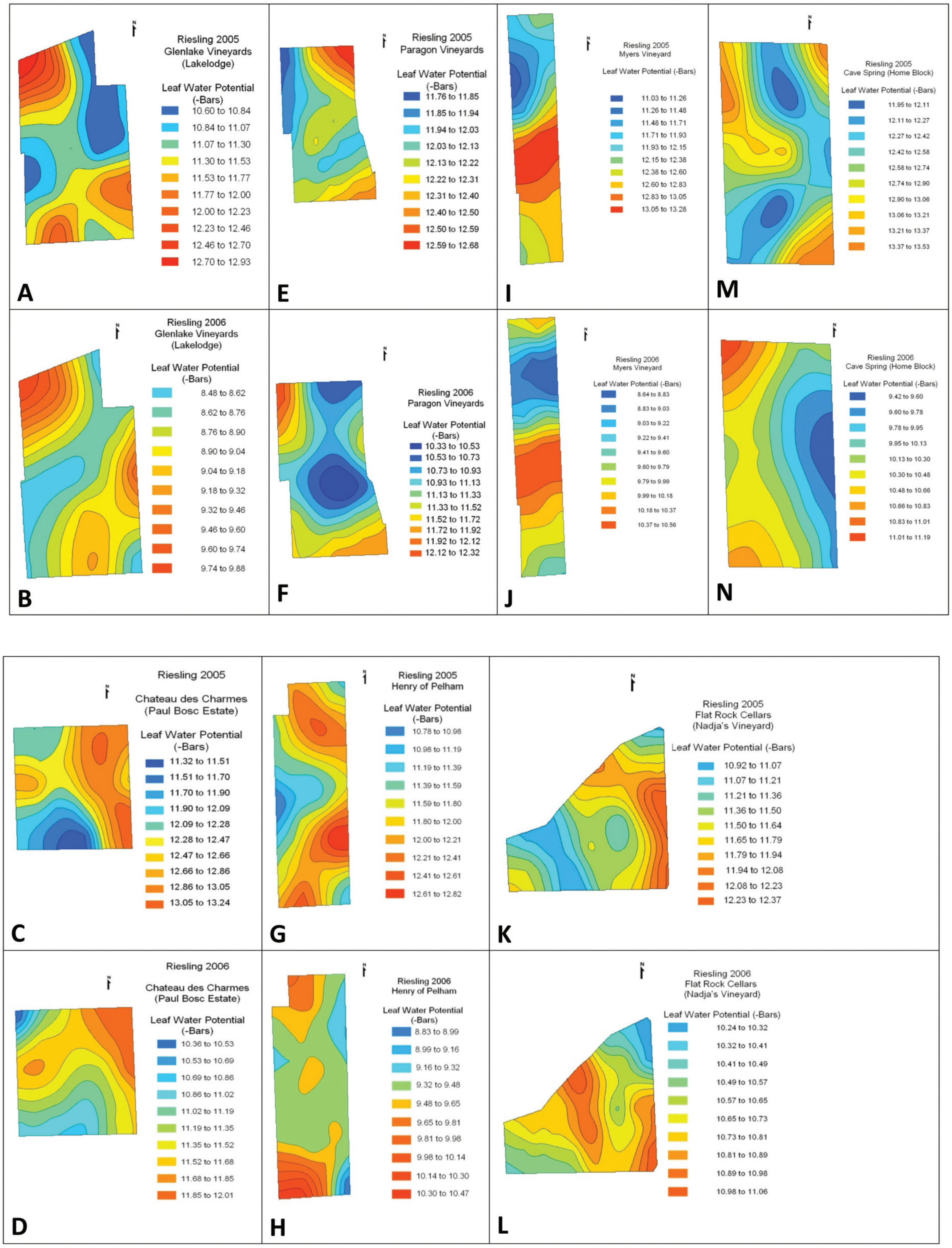

Figure 2. Identification and sorting of Riesling sentinel vines for seven Ontario vineyards, 2005 (A,C,E,G,I,K,M) and 2006 (B,D,F,H,J,L,N) based on vine water status zones on GIS-generated maps. A,B: Glenlake Vineyard, Niagara-on-the-Lake; C,D: Chateau des Charmes Vineyard, St. Davids; E,F: Paragon Vineyard, Jordan; G,H: Henry of Pelham Vineyard, St. Catharines; I,J: Myers Vineyard, Vineland; K,L: Flat Rock Vineyard, Jordan; M,N: Cave Spring Vineyard, Beamsville. Vines in blue/green zones were placed in high water status treatments; vines in orange/red zones were placed in low water status treatments.

Table 2. Means and p-values (< 0.10) for Riesling wines from vines of different water status within ten vineyard sites across the Niagara Peninsula, Ontario, 2005. High water status zones were those with mean seasonal leaf water potential > -1.0 MPa, while low water status zones were those with mean seasonal leaf water potential < -1.3 MPa.

Descriptor	Niagara Lakeshore (Glenlake)			Beamsville Bench (Cave Spring)			St. David's Bench (Ch. Des Charmes)			Twenty Mile Bench (Flat Rock)			Short Hills Bench (Henry of Pelham)		
Aroma															
	LWS [a]	**HWS**	**P**	**LWS**	**HWS**	**P**	**LWS**	**HWS**	**P**	**LWS**	**HWS**	**P**	**LWS**	**HWS**	**P**
Apple/Pear	6.0	6.5	NS	6.1	6.1	NS	6.6	6.1	NS	6.9	5.8	NS	6.7	6.0	NS
Baking Spice	1.4	1.7	NS	1.6	1.5	NS	2.2	2.0	NS	**2.2**	**2.3**	**0.006**	1.9	1.6	NS
Citrus	5.3	5.4	NS	4.4	4.8	NS	5.0	4.3	NS	**5.7**	**3.0**	**0.02**	4.4	4.0	NS
Honey	**2.3**	**1.6**	**0.01**	**6.6**	**4.9**	**0.02**	**5.0**	**2.9**	**0.005**	5.3	5.2	NS	4.8	3.6	NS
Mineral/Flint	**6.1**	**4.8**	**0.10**	5.2	5.4	NS	**6.3**	**4.7**	**0.08**	4.7	3.5	NS	**5.3**	**4.9**	**0.05**
Peach	0.9	0.6	NS	0.7	0.7	NS	0.7	0.7	NS	0.7	0.5	NS	1.1	0.8	NS
Petrol	3.3	2.9	NS	2.6	2.9	NS	**3.3**	**1.8**	**0.03**	2.4	1.5	NS	2.9	2.2	NS
Tropical Fruit	1.9	1.4	NS	**1.9**	**1.2**	**0.09**	1.0	1.0	NS	1.6	1.4	NS	2.0	1.3	NS
Vegetal	3.0	2.3	NS	**0.6**	**1.6**	**0.06**	1.3	1.5	NS	0.6	1.0	NS	**1.4**	**2.5**	**0.05**
Flavor															
Apple/Pear	7.4	7.7	NS	6.1	6.9	NS	**7.3**	**5.8**	**0.04**	**6.5**	**6.6**	**0.04**	8.0	7.4	NS
Citrus	**6.8**	**6.5**	**0.10**	**5.1**	**5.9**	**0.04**	6.2	5.5	NS	**6.5**	**5.0**	**0.01**	**5.4**	**5.2**	**0.03**
Honey	**1.4**	**2.2**	**0.03**	**3.5**	**2.3**	**0.09**	3.5	2.8	NS	**3.5**	**4.0**	**0.04**	**4.5**	**2.9**	**0.02**
Mineral/Flint	4.8	4.0	NS	4.3	4.4	NS	**4.9**	**3.2**	**0.05**	3.3	3.0	NS	3.8	3.8	NS
Peach	1.0	0.8	NS	**0.9**	**0.5**	**0.04**	0.9	0.9	NS	0.9	0.7	NS	1.5	0.9	NS
Petrol	**2.9**	**2.2**	**0.08**	2.0	2.0	NS	2.1	1.6	NS	1.1	0.7	NS	2.5	1.8	NS
Tropical Fruit	1.1	0.9	NS	1.2	1.1	NS	**2.2**	**1.0**	**0.05**	1.6	1.4	NS	**2.2**	**1.1**	**0.03**
Vegetal	2.1	1.6	NS	1.0	0.7	NS	**0.8**	**1.4**	**0.05**	0.2	0.4	NS	0.9	1.9	NS
Taste/ mouthfeel															
Sweet	3.4	3.4	NS	2.8	2.9	NS	**4.6**	**3.4**	**0.05**	**3.4**	**3.2**	**0.04**	**5.6**	**3.9**	**<0.001**
Sour	9.3	9.5	NS	**6.6**	**8.2**	**0.01**	**7.0**	**8.0**	**0.05**	**7.7**	**7.5**	**0.08**	**6.2**	**8.1**	**<0.001**
Bitter	0.7	0.8	NS	0.6	1.0	NS	0.4	0.6	NS	0.1	0.4	NS	0.4	1.1	NS
Astringency	**0.8**	**1.1**	**0.04**	1.3	1.5	NS	1.5	1.8	NS	1.5	2.1	NS	2.3	2.5	NS

[a] LWS, HWS: Low water status, high water status.
[b] No yield in 2005 due to severe winter injury in 2004-2005.

Table 2 (contd.). Means and p-values (< 0.10) for Riesling wines from vines of different water status within ten vineyard sites across the Niagara Peninsula, Ontario, 2005. High water status zones were those with mean seasonal leaf water potential > -1.0 MPa, while low water status zones were those with mean seasonal leaf water potential < -1.3 MPa.

Descriptor	Four Mile Creek (Lambert)			Lincoln Lakeshore (Myers)			Creek Shores (Paragon)			Niagara River (Reif)			Vinemount Ridge (Vailmont)		
	LWS[a]	**HWS**	**P**	**LWS**	**HWS**	**P**	**LWS**	**HWS**	**P**	**LWS**	**HWS**	**P**	**LWS**	**HWS**	**P**
Aroma															
Apple/Pear	---b	---b	---b	**6.4**	**5.9**	**0.009**	5.5	4.5	NS	---b	---b	---b	6.6	6.1	NS
Baking Spice				1.9	1.5	NS	1.1	0.8	NS				**2.5**	**1.4**	**0.05**
Citrus				4.8	4.3	NS	4.3	3.4	NS				5.1	3.8	NS
Honey				**4.9**	**4.1**	**0.04**	2.5	2.4	NS				4.7	2.7	NS
Mineral/Flint				5.9	5.3	NS	5.0	4.5	NS				4.9	4.8	NS
Peach				1.3	0.8	NS	0.5	0.2	NS				1.3	0.7	NS
Petrol				2.6	1.8	NS	**2.5**	**2.8**	**0.05**				3.3	2.7	NS
Tropical Fruit				2.7	1.5	NS	0.7	0.5	NS				**2.6**	**0.6**	**0.06**
Vegetal				**0.8**	**1.5**	**0.09**	1.2	1.9	NS				1.6	3.3	NS
Flavor															
Apple/Pear				**6.4**	**6.1**	**0.05**	**7.0**	**5.1**	**0.007**				**7.7**	**6.4**	**0.03**
Citrus				5.5	5.3	NS	4.8	4.7	NS				6.0	5.6	NS
Honey				**3.2**	**2.7**	**0.09**	2.6	1.5	NS				**3.3**	**2.5**	**0.03**
Mineral/Flint				4.5	4.2	NS	3.8	3.0	NS				4.1	3.6	NS
Peach				1.5	1.0	NS	0.9	0.7	NS				1.2	0.8	NS
Petrol				**2.3**	**1.6**	**0.03**	2.0	1.8	NS				**2.8**	**1.5**	**0.05**
Tropical Fruit				2.0	1.3	NS	0.9	0.5	NS				1.6	0.9	NS
Vegetal				0.8	1.0	NS	0.6	1.1	NS				0.9	1.9	NS
Taste/ mouthfeel															
Sweet				3.4	3.2	NS	**4.5**	**3.1**	**0.02**				2.9	2.7	NS
Sour				**7.3**	**8.7**	**0.04**	**7.3**	**8.8**	**0.03**				**6.6**	**8.2**	**0.006**
Bitter				0.3	0.3	NS	0.4	0.7	NS				0.5	1.2	NS
Astringency				1.5	1.9	NS	1.5	2.0	NS				1.2	1.5	NS

[a] LWS, HWS: Low water status, high water status.
[b] No yield in 2005 due to severe winter injury in 2004-2005.

citrus aroma, mineral/flint flavor, peach flavor and astringency were different in one vineyard site only. In most circumstances, wines from low leaf ψ zones (< -1.2 MPa) displayed enhanced apple/pear, citrus, honey, mineral, petrol, and tropical fruit aromas and flavors, and reduced intensity of vegetal aromas and flavors. Wines from high leaf ψ zones from two sites displayed higher citrus and apple/pear flavors, respectively, while high leaf ψ zones from two other sites showed higher honey flavor. Low leaf ψ wines also commonly had higher sweetness and lower sourness compared to their high leaf ψ (> -1.0 MPa) counterparts

2006: Results from ANOVA are in Table 3. Differences of sensory attributes within vineyards ranged from two to eight aroma and flavor attributes with a median of four. The most common aroma attribute difference within vineyards was vegetal aroma followed by apple/pear, baking spice, mineral/flint and petrol aromas (two sites each). In terms of flavor attributes, tropical fruit and vegetal flavors were the most common descriptors to differ within vineyards (four sites each), followed by apple/pear (three sites), honey (three sites), and peach flavors (two sites). Sweet taste was different within six vineyards while bitter and sour tastes were different in two vineyards. Citrus, honey, peach and tropical aromas were different within one vineyard only. Petrol flavor was a non-factor whereas citrus, mineral/flint flavors and astringency were site specific and only differed within one site. As in 2005, wines from low leaf □ (> -1.0 MPa) zones displayed enhanced apple/pear, citrus, honey, mineral, petrol, and tropical fruit aromas and flavors, and reduced intensity of vegetal aromas and flavors. Low leaf ψ wines also commonly had higher sweetness and lower sourness compared to wines from high leaf ψ (-1.0-1.2 MPa) zones.

3.2 Integration of sensory data across vintages and vineyard sites

There were attributes common to both vintages for wines of similar leaf ψ despite variations in the growing seasons. Yearly variations in some sensory attributes between high and low leaf ψ wines within a vineyard may be related to differences in the mean ψ values of the given year. For example, vines designated as “low water status” had lower ψ values (< -1.3 MPa) in 2005 than those from the 2006 vintage (-1.0-1.2 MPa). Since the fruit was harvested systematically through the use of data imported into GIS software it was possible to assign an actual range of ψ values to each wine as all the grapes used in production of the wine treatment would fall into that particular criteria. Furthermore, the wines were both viticulture and enological replicates and there was no amalgamation during winemaking, so the fruit/wine’s geographic location could be accounted for within the vineyard site.

ANOVA 2005: Collectively across sites, wines made from vines with the highest leaf ψ (> -1.0 MPa) had lowest intensity ratings for apple/pear, honey, mineral, and tropical fruit aromas and flavors but had the highest vegetal aromas and flavors as well as sourness (Table 2). Conversely, wines produced from vines of the lowest leaf ψ category (< -1.3 MPa) were highest in honey, tropical fruit and petrol aromas and flavors and lowest in vegetal aromas and flavors. Wines made from fruit produced under mild water deficit (-1.0 to -1.2 MPa) had sensory profiles highest in mineral/flint, petrol, and honey aromas and apple/pear flavor (data not shown). There were few differences in terms of baking spice aroma, mineral and peach flavors as well as astringency and bitterness.

ANOVA 2006: Since the 2006 vintage was cooler and wetter than 2005, there were less vineyards with vines experiencing moderate to high water deficits (Table 3). Wines produced from vines > -1.0 MPa had sensory profiles with the lowest apple/pear aroma/flavor, baking spice aroma, honey and tropical fruit flavors, and highest vegetal aromas and flavors, as well as sourness and bitterness. Wines made from vines that experienced mild deficit (-1.0 to -1.2 MPa) had the highest apple/pear, tropical fruit, mineral/flint aromas and flavors, and lowest vegetal aroma/flavor. There were no large differences in many of the aroma and flavor attributes in 2006. Citrus, tropical fruit, peach and honey aromas as well as citrus, mineral and petrol flavors did not discriminate the wine treatments. Some of these results can be explained by rainfall events late in the growing season including the harvest period. These significant rain events possibly mitigated many of the leaf ψ differences that were observed during the growing season, hence influencing the final quality of the wines. Still, some consistent trends were found; wines made from vines of mild water deficit (-1.0 to -1.2 MPa) had more mineral/flint and petrol aromas as well as honey flavor, while wines produced from vines with no water deficit had more vegetal aromas and flavors.

Summary of 2005-2006 vintages: Categorizing wines based on absolute leaf ψ, as opposed to the lowest and highest leaf ψ category within each site, allowed interpretation of the results of within site-differences across all vineyards and vintages. Wines produced from vines with leaf ψ > -1.0 MPa had sensory profiles with the highest intensity ratings of vegetal aromas and flavors. These wines also had the lowest honey and petrol aromas. On the contrary, wines made from vines < -1.3 MPa were highest in honey, petrol and tropical fruit flavors and lowest in vegetal aromas and flavors.

Most sensory descriptors were appropriate for this study. In terms of aroma attributes, citrus and peach aromas were site specific and not very important descriptors to discriminate Riesling wines of different leaf ψ. Mineral/flint flavors and astringency were also not of much importance in terms of their discriminatory characteristics of the wines. White wines are not normally described as being astringent; however, in cooler climates Riesling wines can have quite high acidity (i.e. some wines in this study had TA > 13 g/L and pH < 2.9). Acids have been shown to elicit tactile sensations such as astringency (Thomas and Lawless, 1995); therefore, it was a valid descriptor but was not very important from a discriminatory point of view in this study.

3.3 IPrincipal components analysis

PCA was used to help interpret the results of the significant sensory attributes within each vineyard site. Chemical variables of the must were used as supplementary variables to see their relationship although most did not differ substantially between vine leaf ψ treatments (data not shown). The PCA biplots for individual vineyards are shown in Figures 3 to 9. In both vintages wines of similar leaf ψ were clustered together with similar sensory characteristics. Sites for which both vintages were unavailable due to disease or winter injury are not depicted.

2005: The PCA performed using significant sensory attributes of leaf ψ treatments within the Glenlake Vineyard (Figure 3A) accounted for 78.2% of the variance in the first two PCs (51.1% PC1; 27.1% PC2). All high leaf ψ replicates were located on the positive side of PC2 and associated with honey aroma, honey and citrus flavors, and astringency, as well as with secondary variables Brix, TA, pH, FVT, and PVT. The association with terpenes may relate to some of the more fruit-driven aromas of the wines. Low leaf ψ wines were located on the negative side of PC2 and associated with mineral, petrol, and tropical fruit descriptors. The PCA for Chateau des Charmes (Figure 4A) accounted for 83.2% of the variance in the first two PCs (61.8% PC1; 21.3% PC2). High leaf ψ replicates 1 and 3 (R1, R3) were located in the lower left quadrant and were associated with honey aroma and apple/pear flavor as well as with PVT, whereas R2 was associated with vegetal and mineral/flint flavors and sour taste. Low leaf ψ R1 and R3 were associated with petrol and mineral/flint aromas plus Brix, FVT, and pH, whereas R2 was associated with higher intensity of tropical fruit flavor and sweet taste plus TA. The PCA for Henry of Pelham (Figure 5A) accounted for 83.6% of the variance in the first two PCs (60.9% PC1; 22.7% PC2). High and low leaf ψ wines were well separated by PC2 with high leaf ψ associated with citrus, mineral/flint, and vegetal aromas, citrus flavor, and sour, plus TA, pH, and FVT. Low leaf ψ wines were characterized by honey aroma, honey and tropical fruit flavors, and sweetness, plus Brix and PVT. The PCA for Paragon Vineyard (Figure 6A) accounted for 92.5% of the variance in the first two PCs (72.7% PC1; 19.8% PC2). High and low leaf ψ wines were well separated by PC2 with high leaf ψ (left of PC2) associated with petrol aroma and sourness plus Brix and pH, and low leaf ψ wines characterized by apple/pear flavor and sweetness plus TA, FVT and PVT. The PCA for Flat Rock site (Figure 7A) accounted for 82.8% of the variance in the first two PCs (46.9% PC1; 35.9% PC2). Two high leaf ψ replicates (R1, R3) were located left of PC2 and associated with baking spice aroma, apple/pear and honey flavors, and sweetness, plus TA, and one in the upper right quadrant associated with Brix and FVT. All low leaf ψ wines were located in the lower right quadrant and were associated with citrus aroma and flavor, sourness, pH, and PVT. PCA for the Myers site explained 71.3% of the variance in the first two PCs (46.3% PC1; 24.9% PC2) (Figure 8A) Wines of high leaf ψ were located above PC1 and were characterized by apple/pear and vegetal aromas and apple/pear and sour flavors, plus Brix and PVT, whereas wines of low leaf ψ (located below PC1) were associated with honey aroma and petrol, honey and peach flavors plus TA, pH, and FVT. PCA for Cave Spring explained 87.1% of the variance in the first two PCs (53.8% PC1; 33.9% PC2) (Figure 9A) Wines of high leaf ψ were located on the positive side of PC1 and were characterized by citrus and honey aromas, apple/pear, citrus, honey, and peach flavors, and sourness, plus Brix and pH. Wines of low leaf ψ (located on the negative side of PC1) were associated with tropical fruit aroma, TA, FVT and PVT.

2006: The PCA performed using significant sensory attributes of leaf ψ treatments within the Glenlake site (Figure 3B) accounted for 83.3% of the variance in the first two PCs (55.8% PC1; 27.5% PC2). All high leaf ψ replicates were located on the positive side of PC2 (as in 2005) and were associated with petrol and vegetal aromas and vegetal flavor plus TA and FVT. Low leaf ψ wines were left of PC2 and associated

Table 3. Means and p-values (< 0.10) for Riesling wines from vines of different water status within ten vineyard sites across the Niagara Peninsula, Ontario, 2006. High water status zones were those with mean seasonal leaf water potential > -1.0 MPa, while low water status zones were those with mean seasonal leaf water potential of -1.0-1.2 MPa.

Descriptor	Niagara Lakeshore (Glenlake)			Beamsville Bench (Cave Spring)			St. David's Bench (Ch. Des Charmes)			Twenty Mile Bench (Flat Rock)			Short Hills Bench (Henry of Pelham)		
							Aroma								
	LWS[a]	HWS	P	LWS	HWS	P	LWS	HWS	P	LWS	HWS	P	LWS	HWS	P
Apple/Pear	5.6	5.3	NS	5.1	4.3	NS	**5.7**	**4.8**	**0.001**	5.5	4.9	NS	5.6	5.1	NS
Baking Spice	2.7	2.3	NS	**3.9**	**2.5**	**0.05**	3.6	2.4	NS	**3.4**	**3.0**	**0.01**	3.2	2.6	NS
Citrus	4.2	3.8	NS	3.8	3.5	NS	4.3	3.9	NS	4.2	3.3	NS	**4.4**	**3.5**	**0.02**
Honey	2.7	2.1	NS	2.8	2.2	NS	3.0	2.3	NS	2.6	2.6	NS	2.7	2.3	NS
Mineral/Flint	4.4	4.2	NS	4.0	4.0	NS	4.4	4.1	NS	4.6	3.9	NS	4.7	4.3	NS
Peach	1.8	1.3	NS	1.1	0.9	NS	1.5	0.9	NS	1.1	1.0	NS	1.7	1.2	NS
Petrol	2.6	1.9	NS	**1.6**	**0.9**	**0.09**	2.0	1.3	NS	2.0	1.5	NS	1.9	2.4	NS
Tropical Fruit	3.0	1.9	NS	**2.7**	**1.5**	**0.08**	2.6	1.9	NS	1.6	2.0	NS	3.0	2.0	NS
Vegetal	**1.7**	**2.7**	**0.07**	**0.9**	**1.9**	**0.07**	1.0	1.9	NS	**1.9**	**0.8**	**0.02**	1.7	2.0	NS
							Flavor								
Apple/Pear	5.9	5.1	NS	5.1	5.3	NS	**6.0**	**4.9**	**0.05**	5.9	5.7	NS	**5.9**	**4.8**	**0.03**
Citrus	5.9	5.0	NS	4.8	4.0	NS	4.8	4.5	NS	5.3	5.0	NS	5.8	5.3	NS
Honey	**2.6**	**1.9**	**0.03**	2.8	2.2	NS	**2.5**	**1.7**	**0.07**	2.0	2.1	NS	2.3	2.0	NS
Mineral/Flint	4.3	4.4	NS	3.8	3.4	NS	4.3	4.0	NS	4.5	4.2	NS	4.6	4.3	NS
Peach	1.3	1.2	NS	**1.5**	**0.8**	**0.03**	**1.8**	**0.9**	**0.02**	1.2	1.1	NS	1.3	1.1	NS
Petrol	1.7	1.6	NS	1.6	1.2	NS	1.6	1.7	NS	1.8	1.5	NS	1.8	1.6	NS
Tropical Fruit	2.2	1.6	NS	**2.8**	**1.9**	**0.004**	**2.7**	**1.5**	**0.05**	1.7	1.7	NS	2.6	1.7	NS
Vegetal	**1.3**	**1.9**	**0.07**	**0.6**	**0.7**	**0.10**	1.0	1.3	NS	1.3	1.5	NS	**1.0**	**1.5**	**0.04**
							Taste/ mouthfeel								
Sweet	1.3	1.3	NS	**3.9**	**2.8**	**<0.001**	**2.3**	**1.5**	**0.02**	1.3	1.3	NS	**1.5**	**1.2**	**0.009**
Sour	7.6	7.9	NS	6.7	7.1	NS	**7.2**	**7.8**	**0.009**	7.8	8.0	NS	7.5	8.0	NS
Bitter	1.0	1.3	NS	0.8	0.7	NS	**0.9**	**1.2**	**0.06**	1.1	1.0	NS	0.8	1.2	NS
Astringency	1.8	1.9	NS	1.7	1.7	NS	1.6	1.8	NS	1.8	2.0	NS	1.8	1.9	NS

[a] *LWS, HWS: Low water status, high water status.*
[b] *No yield in 2006 due to severe powdery mildew.*

Table 3 (contd.). Means and p-values (< 0.10) for Riesling wines from vines of different water status within ten vineyard sites across the Niagara Peninsula, Ontario, 2006. High water status zones were those with mean seasonal leaf water potential > -1.0 mPa, while low water status zones were those with mean seasonal leaf water potential of -1.0-1.2 MPa.

Descriptor	Four Mile Creek (Lambert)			Lincoln Lakeshore (Myers)			Creek Shores (Paragon)			Niagara River (Reif)			Vinemount Ridge (Vailmont)		
Aroma															
	LWS[a]	HWS	P	LWS	HWS	P	LWS	HWS	P	LWS	HWS	P	LWS	HWS	P
Apple/Pear	5.7	5.3	NS	4.9	3.9	NS	5.6	5.4	NS	**6.3**	**5.2**	**0.08**	---b	---b	---b
Baking Spice	2.5	1.7	NS	3.7	2.5	NS	3.2	2.8	NS	2.9	2.4	NS			
Citrus	4.2	3.0	NS	3.3	2.9	NS	4.1	3.7	NS	3.8	3.8	NS			
Honey	2.6	1.9	NS	**3.3**	**1.9**	**0.05**	2.8	2.8	NS	3.2	2.5	NS			
Mineral/Flint	4.7	3.5	NS	**4.5**	**3.5**	**0.09**	4.6	3.8	NS	**5.0**	**4.4**	**0.008**			
Peach	1.7	1.4	NS	**1.2**	**0.7**	**0.06**	1.7	1.2	NS	1.2	1.0	NS			
Petrol	**2.3**	**1.6**	**0.03**	1.8	1.4	NS	1.6	1.8	NS	2.6	2.1	NS			
Tropical Fruit	3.3	2.8	NS	2.9	1.8	NS	2.3	2.1	NS	2.8	2.0	NS			
Vegetal	1.4	2.1	NS	**1.3**	**3.0**	**0.04**	1.2	1.9	NS	1.1	1.4	NS			
Flavor															
Apple/Pear	6.1	5.4	NS	5.8	4.6	NS	**6.8**	**5.8**	**0.09**	6.5	5.9	NS			
Citrus	5.3	4.4	NS	**5.2**	**4.8**	**<0.001**	5.4	4.9	NS	5.5	5.5	NS			
Honey	2.6	1.8	NS	2.2	1.4	NS	2.8	2.3	NS	**2.9**	**2.0**	**0.05**			
Mineral/Flint	4.3	3.0	NS	4.8	3.8	NS	**4.2**	**3.2**	**0.01**	4.4	4.2	NS			
Peach	1.9	1.3	NS	1.1	0.9	NS	1.3	1.3	NS	1.3	1.0	NS			
Petrol	2.9	2.6	NS	2.0	1.1	NS	1.7	1.5	NS	1.9	1.3	NS			
Tropical Fruit	3.2	2.3	NS	2.2	1.1	NS	**2.7**	**2.4**	**0.09**	**2.7**	**1.7**	**0.07**			
Vegetal	1.1	1.8	NS	0.9	2.0	NS	1.1	1.5	NS	**0.8**	**1.2**	**0.07**			
Taste/ mouthfeel															
Sweet	**1.7**	**1.3**	**0.03**	**1.8**	**1.1**	**0.03**	**1.9**	**1.5**	**0.005**	1.8	1.3	NS			
Sour	7.6	8.1	NS	6.9	7.6	NS	7.9	8.1	NS	**7.5**	**8.0**	**0.05**			
Bitter	1.3	1.7	NS	1.0	1.1	NS	1.0	1.3	NS	**1.0**	**1.5**	**0.05**			
Astringency	1.7	1.7	NS	**1.5**	**2.0**	**0.06**	1.9	1.9	NS	1.7	2.0	NS			

[a] *LWS, HWS: Low water status, high water status.*
[b] *No yield in 2006 due to severe powdery mildew.*

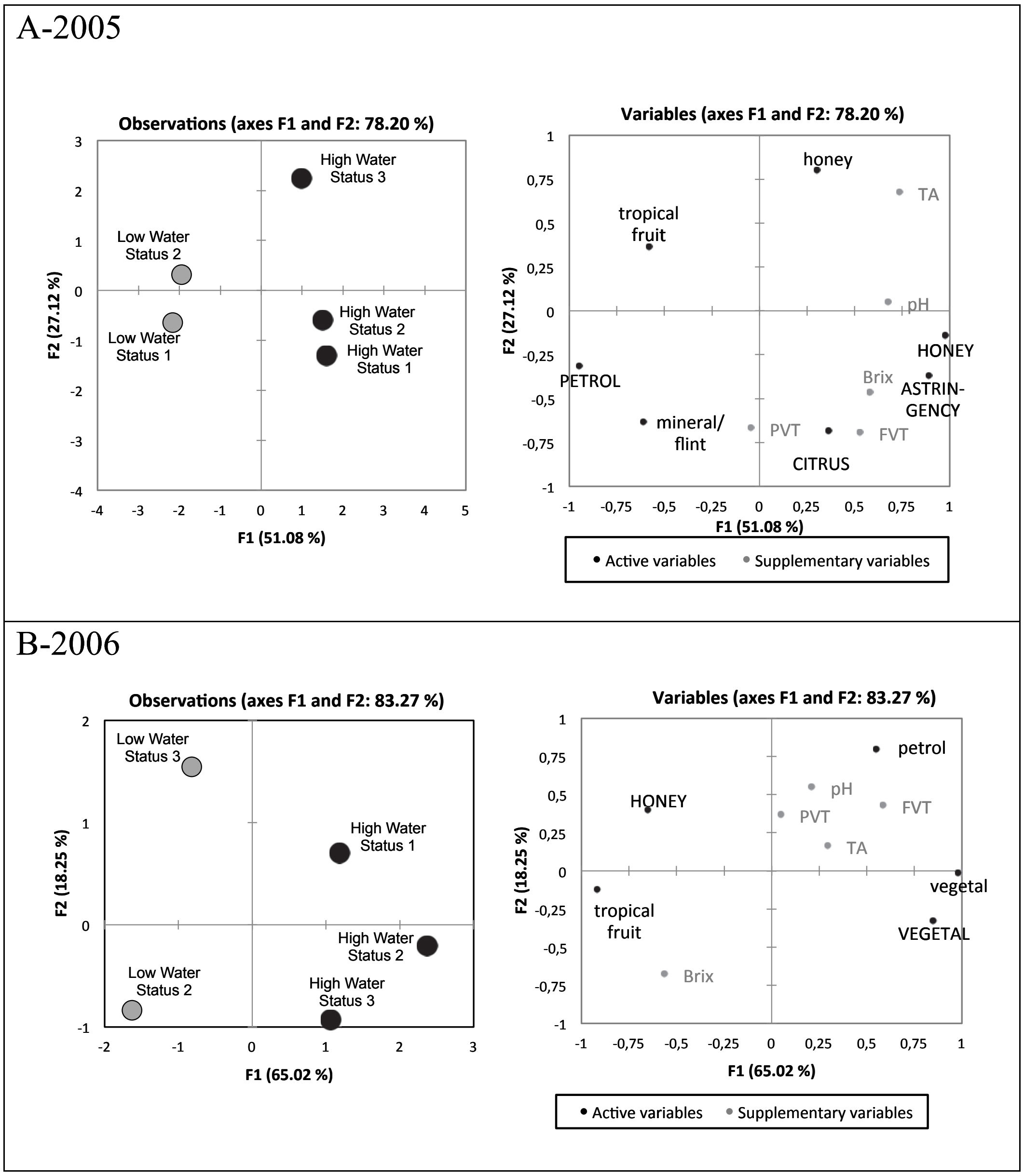

Figure 3. Principal component analysis for Riesling wines, Glenlake Vineyard, Niagara-on-the-Lake, ON depicting intensity ratings of significant attributes on principal components (PC1 and PC2), 2005 (A) and 2006 (B). Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

with tropical fruit aroma and honey flavor plus Brix, pH and PVT. The PCA for Chateau des Charmes (Figure 4B) accounted for 88.2% of the variation in the first two PCs (64.7% PC1; 23.6% PC2). Clustering of treatments was more discrete than in 2005. High leaf ψ wines were left of PC2 (R1 slightly to the right) and were associated with apple/pear aroma and flavor (R1) and sour and bitter taste (R2 and R3), plus TA, pH, FVT, and PVT. Low leaf ψ wines were located in the lower right quadrant and associated with peach and honey flavors as well as sweet taste and Brix. The PCA for Henry of Pelham (Figure 5B) accounted for 69.5% of the variation in the first two PCs (42.6% PC1; 26.9% PC2). Leaf ψ replicates were not as well clustered as in 2005; high leaf ψ wines were somewhat clustered on or below PC1 and associated with apple/pear and citrus aromas and apple/pear, petrol, and vegetal flavors, plus Brix, TA, pH, and FVT, while low leaf ψ wines (R1 and R2) were above PC1 and associated with tropical fruit aroma, honey and tropical fruit flavors, sweetness, sourness, and bitterness, plus PVT; low leaf ψ R3 was in the lower right quadrant and characterized similarly to the high leaf ψ wines. The

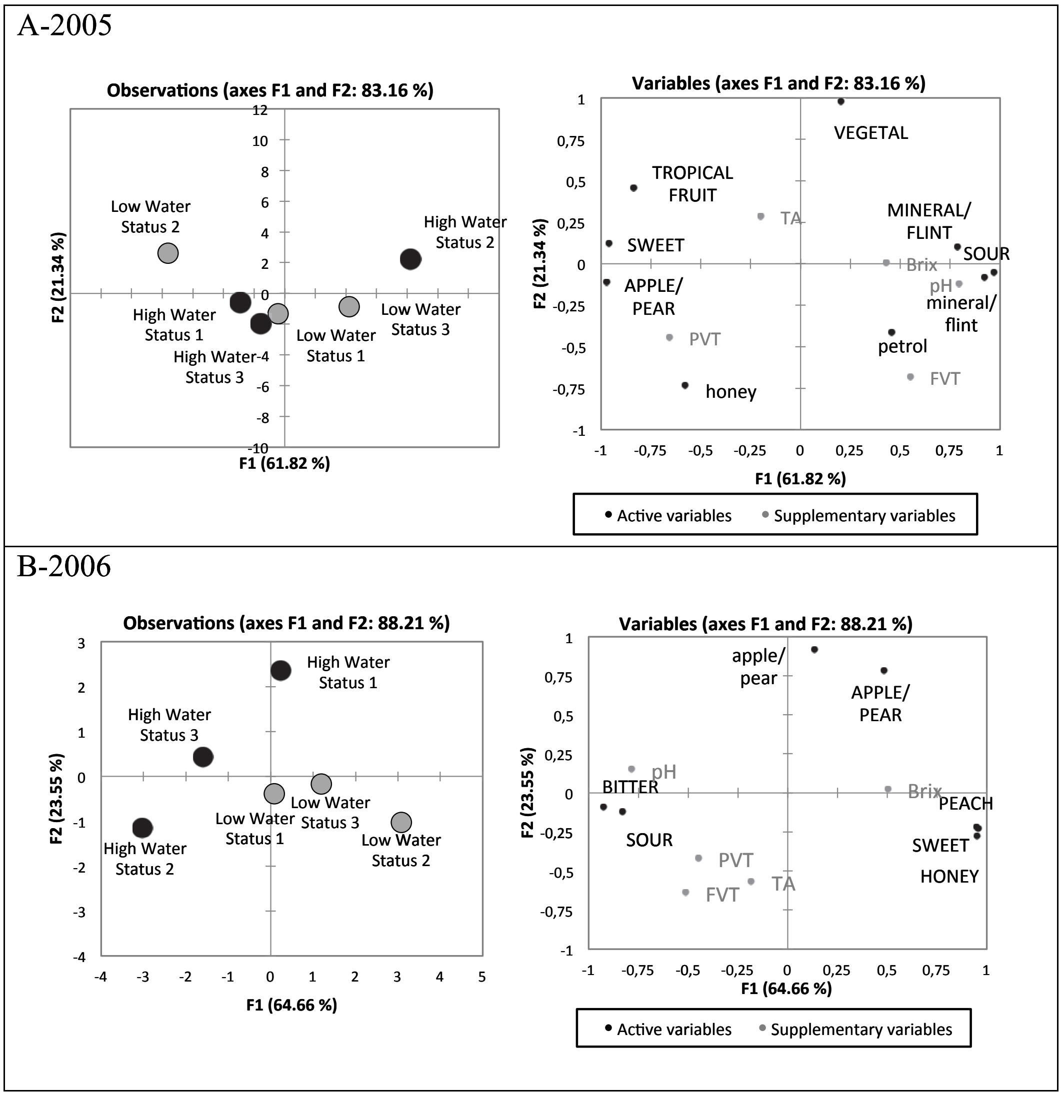

Figure 4. Principal component analysis for Riesling wines, Chateau des Charmes Vineyard, St. Davids, ON depicting intensity ratings of significant attributes on principal components (PC1 and PC2), 2005 (A) and 2006 (B). Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

PCA for Paragon Vineyard (Figure 6B) accounted for 85.8% of the variation with the first two PCs (47.7% PC1; 38.2% PC2). High leaf ψ wines (as with 2005) were on the negative side of PC2 (R1 slightly to the right) and were associated with vegetal aroma and flavor plus Brix, TA and PVT. Low leaf ψ wines were characterized by apple/pear and mineral/flint flavors, sweetness, pH, and FVT. The PCA for the Flat Rock Vineyard (Figure 7B) accounted for 85.9% of the variation with the first two PCs (53.9% PC1; 32.0% PC2). High leaf ψ wines were to the negative side of PC2 (better clustered than 2005) and were associated with baking spice aroma and pH; low leaf ψ wines were on the positive side of PC2 and associated with vegetal aroma and flavor, bitterness, Brix, TA, FVT and PVT. The PCA for the Myers Vineyard accounted for 72.7% of the variation in the first two PCs (48.9% PC1; 23.7% PC2) (Figure 8B). As in 2005, high leaf ψ wines were located on the positive side of PC1 and associated with citrus, honey, and peach aromas, apple/pear and citrus flavors, astringency as well as TA and PVT. Low leaf ψ wines (R1 and R3) were below PC1 and associated with mineral/flint and vegetal aromas and petrol, tropical fruit, mineral/flint and sweet flavors plus Brix, pH and FVT (mainly R3). The PCA for the Cave Spring Vineyard accounted for 66.5% of the variation in the first two PCs (40.6% PC1; 25.9% PC2) (Figure 9B). Wines were not as well clustered as in 2005; two high leaf ψ wines (R1 and R2) were on the positive side of PC2 and R3 was on the negative side. Replicates 1 and 2 were associated with baking spice and tropical fruit aromas, peach and tropical fruit flavors, and sweetness. Two of three

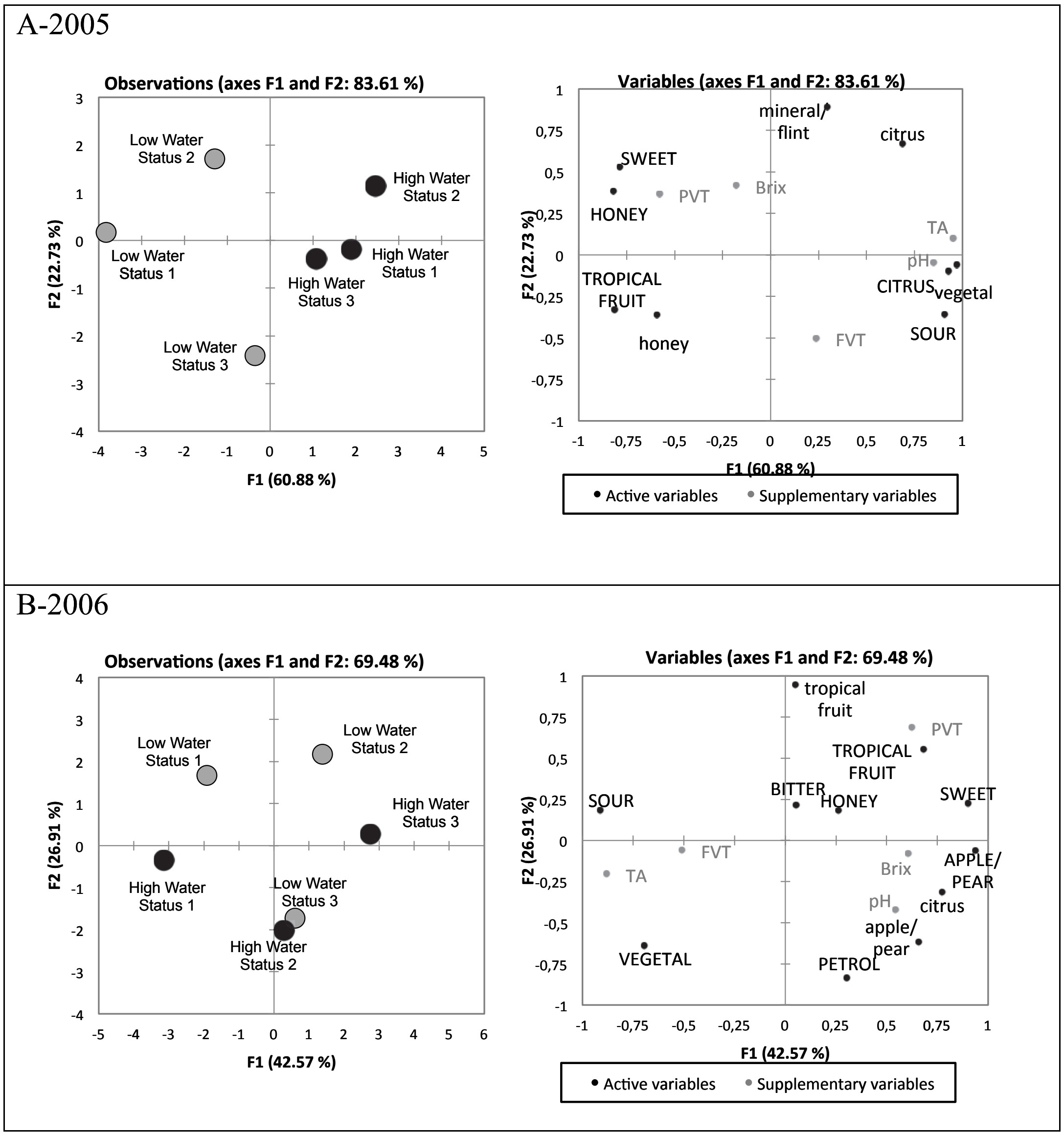

Figure 5. Principal component analysis for Riesling wines, Henry of Pelham Winery, St. Catharines, ON depicting intensity ratings of significant attributes on principal components (PC1 and PC2), 2005 (A) and 2006 (B). Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

low leaf ψ replicates (R2 and R3) were on the negative side of PC1 and characterized by baking spice and tropical fruit aromas, sourness, plus Brix, TA, pH and FVT.

3.4 Integration of sites and vintages

Through examination of leaf ψ values for both vintages of the wines depicted in individual PCA biplots (i.e. Figures 3, 4, 5, 6, 7, 8 et 9), wines of values < -1.2 MPa had more honey, tropical and petrol, and sweet intensity ratings, wines > -1.0 MPa had more vegetal, citrus, apple, sour and astringent intensity ratings, whereas the wines between these two categories had more peach, petrol and mineral aroma/flavor characteristics (Figure 10) Therefore, the entire data set was used for those sensory attributes that were different within sites. Only sensory attributes that were different in at least two vineyard sites for that particular vintage were used to reduce the effect of site specific sensory attributes. Categories were assigned to different leaf ψ values. These included no water deficit (> -1.0 MPa), mild water deficit (-1.0 to -1.3 MPa), and moderate to severe water deficit (< -1.3 MPa). Means were then calculated for intensity ratings of relevant sensory attributes for each category based on the vineyard treatment replicates and their leaf ψ range.

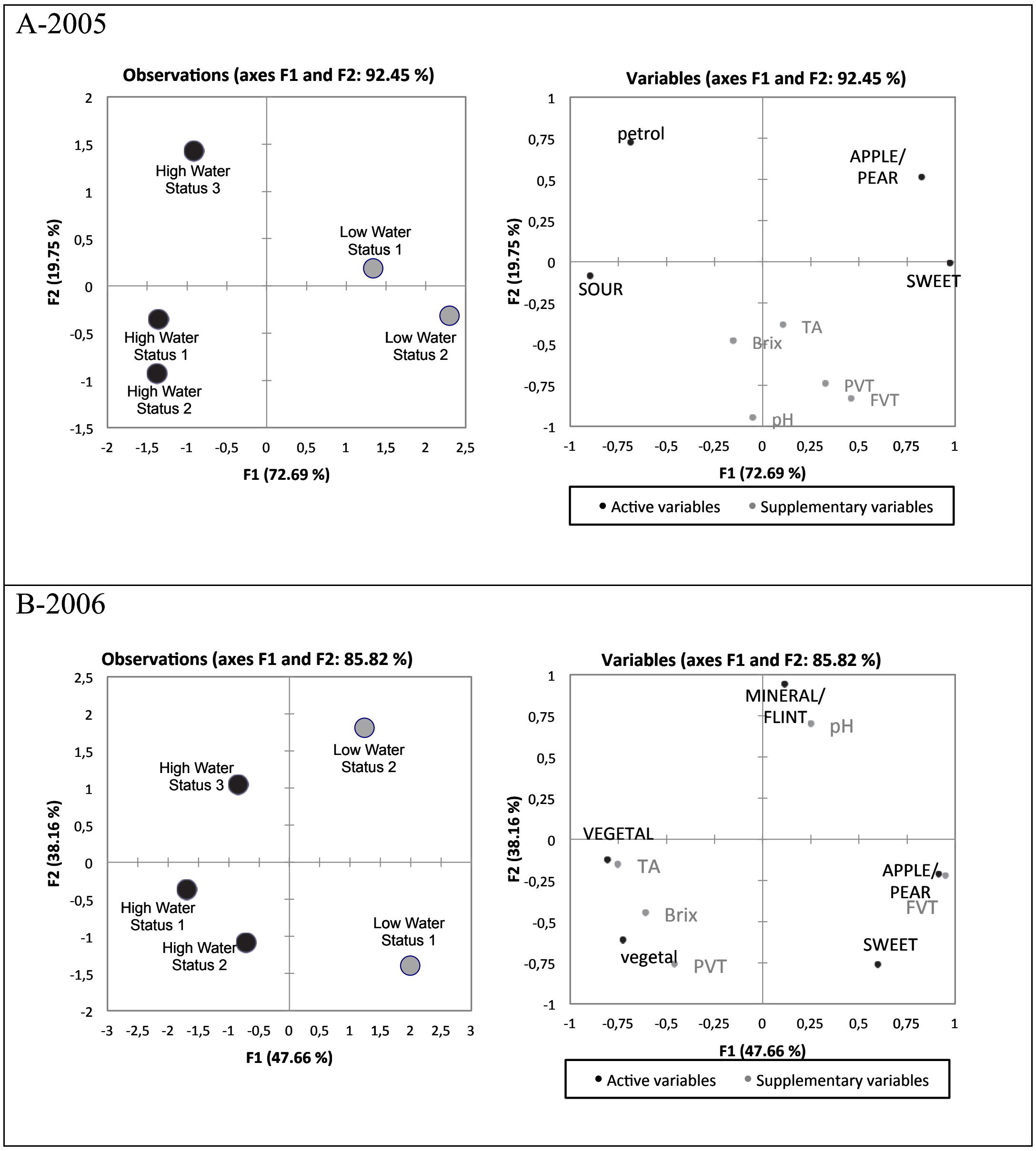

Figure 6. Principal component analysis for Riesling wines, Paragon Vineyard, St. Catharines, ON depicting intensity ratings of significant attributes on principal components (PC1 and PC2), 2005 (A) and 2006 (B). Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

35 IPartial least squares analysis

2005: Partial least squares was used to investigate relationships between vine leaf ψ and viticulture variables and sensory characteristics and help interpret and explain the different sensory characteristics found due to leaf ψ differences within vineyards throughout the Niagara Peninsula. Use of PLS explained 43.0% of the variability in X and 25.2% in Y from the 2005 data set (Figure 11).. Leaf ψ was correlated with vine size, berry weight, yield and % sand, and was associated with higher intensities of vegetal character, citrus and apple/pear flavor. Lower leaf ψ was associated with more honey character.

2006: Use of PLS explained 54.4% of the variability in X and 22.9% in Y from the 2006 data set (Figure 12). As in 2005, leaf ψ was correlated with vine size and yield. Leaf ψ was associated with higher intensities of vegetal character, mineral/flint aroma and petrol flavor. Lower leaf ψ was associated with honey and tropical fruit character. From these data, as in the case of the 2005 vintage, leaf ψ had a significant association with vine performance and the sensory characteristics of Riesling wines.

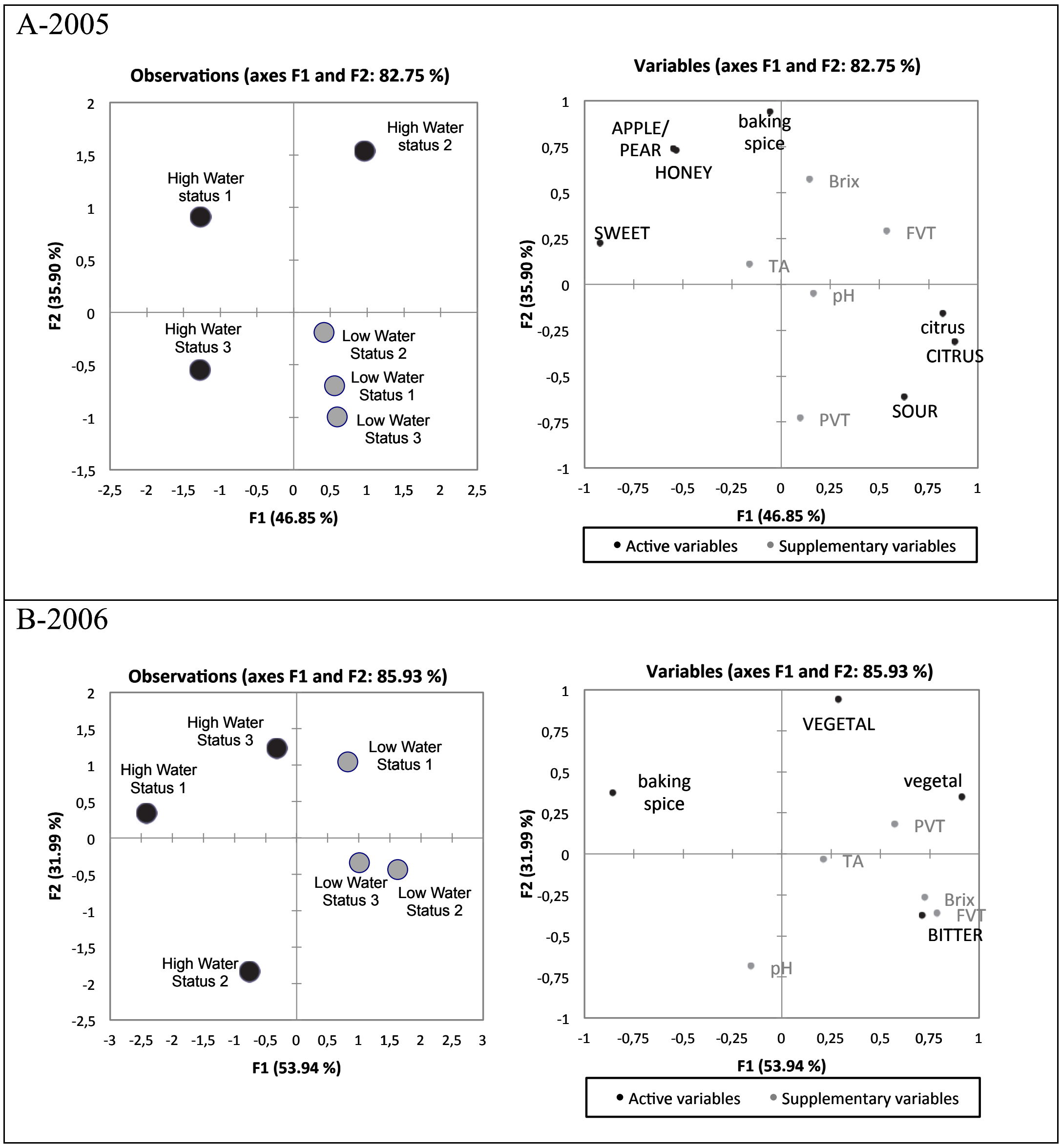

Figure 7. Principal component analysis for Riesling wines, Flat Rock Vineyard, Jordan, ON depicting intensity ratings of significant attributes on principal components (PC1 and PC2), 2005 (A) and 2006 (B). Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

Discussion

These data support our hypothesis that vine water status has a substantial impact on the sensory properties of Riesling wines. Variability of leaf ψ within vineyard sites (regardless of size) led to wines that differed in their sensory profiles. These findings were also consistent among vineyards across the Niagara Peninsula. Many sensory differences were consistent over many vineyards while some other attributes were site specific or insignificant. The results support other studies that show the dependence of wine sensory attributes on vine water status (Chapman *et al.*, 2005; Matthews *et al.*, 1990). In those studies irrigation treatments were performed on the vines. Other studies in Ontario with non-irrigated Riesling (Marciniak *et al.*, 2013), Pinot noir (Ledderhof *et al.*, 2014), and Cabernet franc (Hakimi and Reynolds, 2010) likewise confirmed a substantial dependence of wine sensory attributes upon vine water status. Since no treatment manipulations were imposed onto the vines in this study, this strongly suggests that naturally-occurring vine water status is a major determinant of the terroir effect. This also supports other European terroir-related studies which indicated that water availability and plant water status are the means by which terroir affects wine style and quality (Koundouras *et al.*, 1999;

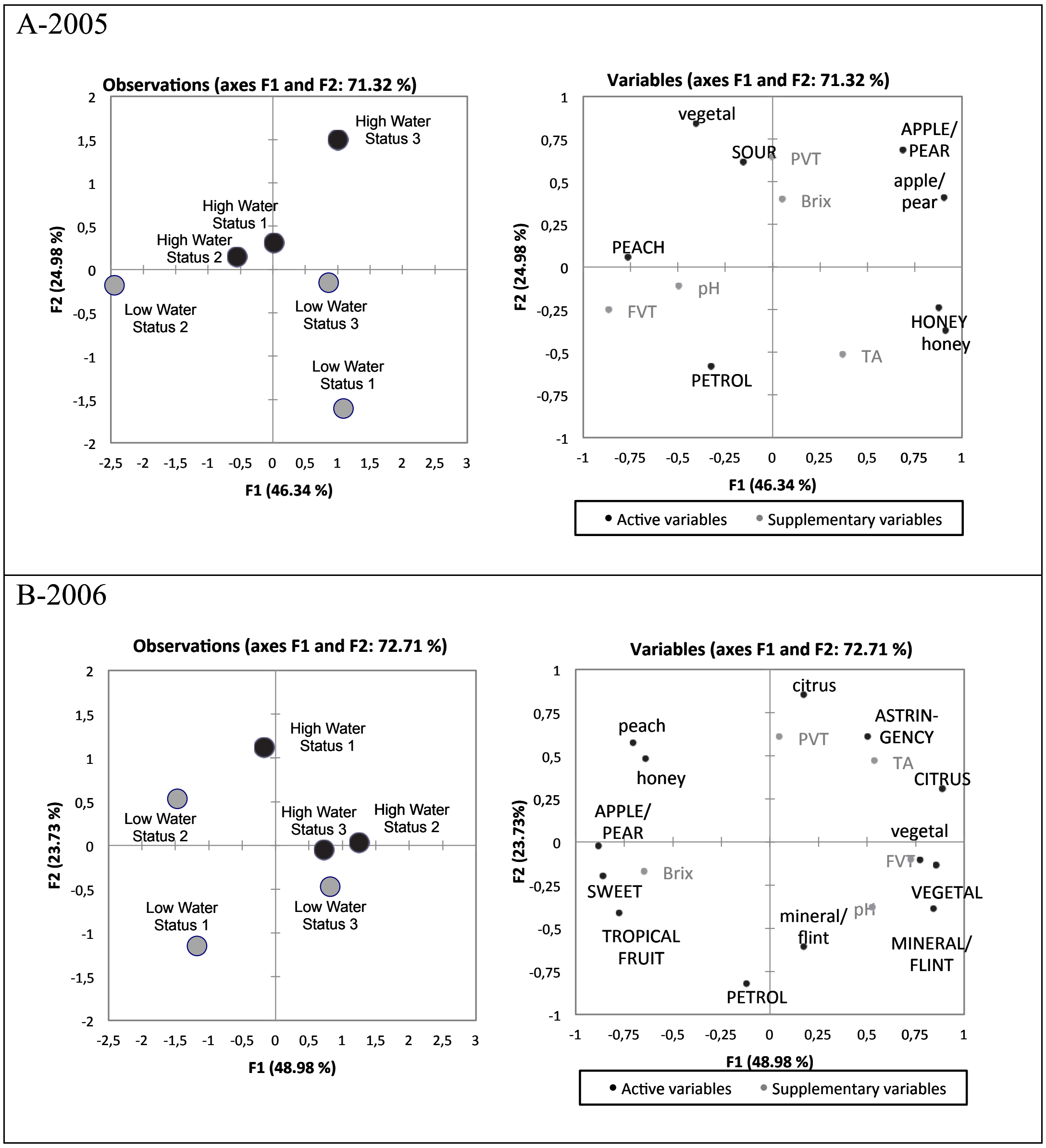

Figure 8. Principal component analysis for Riesling wines, Myers Vineyard, Vineland, ON depicting intensity ratings of significant attributes on principal components (PC1 and PC2), 2005 (A) and 2006 (B). Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

Penavayre *et al.*, 1991; Peyrot des Gachons *et al.*, 2005; Seguin, 1983; van Leeuwen *et al.*, 2009). This is among the first studies in a non-traditional wine region that supports this notion.

Wines from higher leaf ψ zones had more vegetal, and occasionally more citrus and apple/pear character. These wines did not appear to have many of the complexities or characteristics associated with Riesling wines, especially the presence of vegetative character. These findings are similar to those of Penavayre *et al.* (1991) who found that vines with unlimited water supply throughout the growing season resulted in wines that had less intense varietal character. High water status due to an abundant water supply has been shown to be detrimental to grape and wine quality in research for many years. Grapevines with an abundant water supply produce a dense, shaded canopy that reduces wine grape quality (Smart, 1974). Shading retards fruit maturation and can lead to unripe flavors due to methoxypyrazine formation as well as slower methoxypyrazine degradation (Hashizume and Samuta, 1999). On the contrary, mild water deficits are normally beneficial to grape and wine quality. The more fruit forward wines were those of lower leaf ψ zones (< -1.0 MPa).

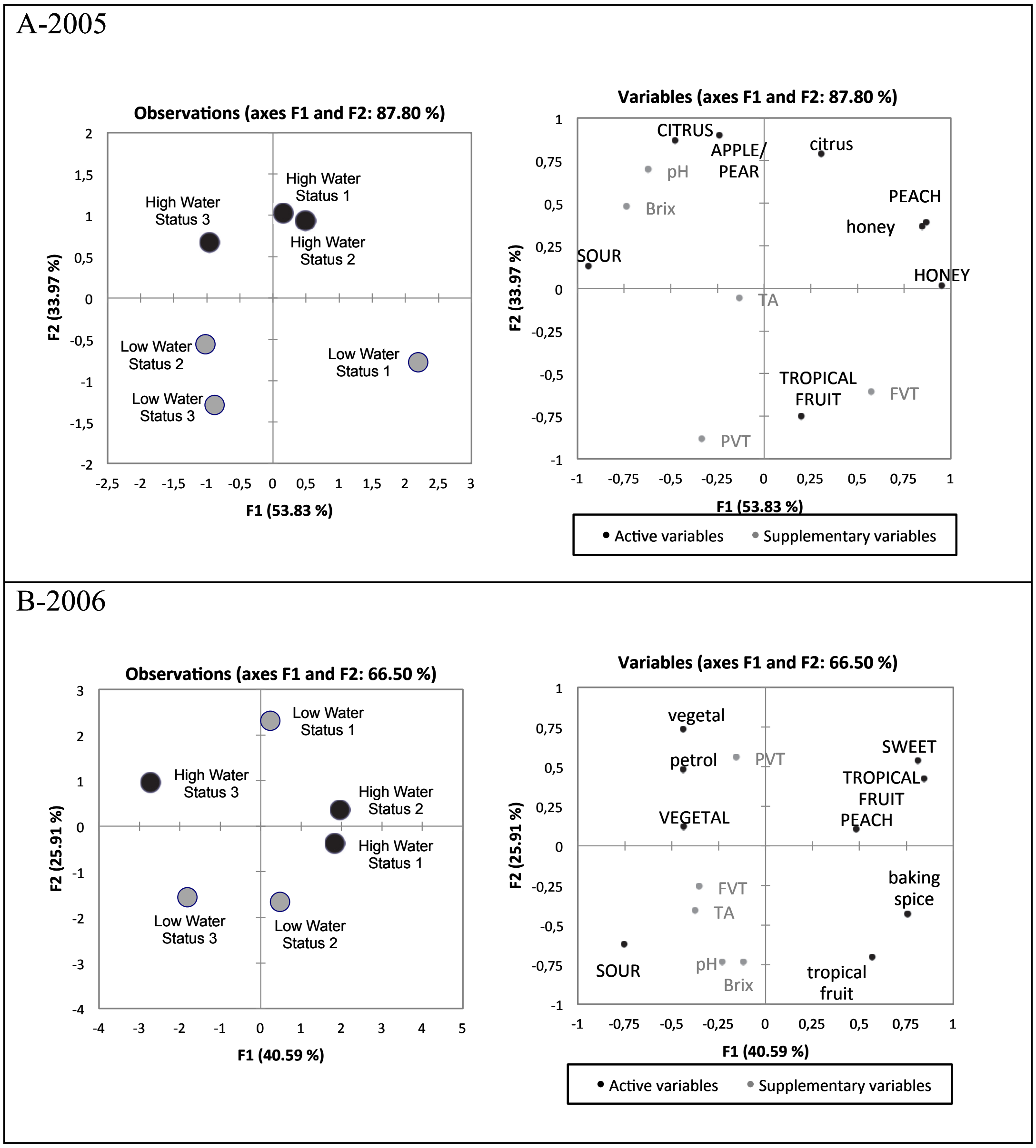

Figure 9. Principal component analysis for Riesling wines, Cave Spring, Beamsville, ON depicting intensity ratings of significant attributes on principal components (PC1 and PC2), 2005 (A) and 2006 (B). Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

This is consistent with studies involving red wine cultivars (Chapman *et al.*, 2005; Hakimi and Reynolds, 2010; Ledderhof *et al.*, 2014) and Noble *et al.* (1995) who found more fruit-driven wines from soils with less water holding capacity and lower water status. Treatments resulting in higher vine water status and soils with more available water produced more vegetative wines.

Vines that experienced some water deficit had the highest intensities of many of the desirable attributes in Riesling wines including honey, mineral/flint, tropical fruit, and petrol and lowest in vegetal aromas, which would not be considered an ideal sensory characteristic in Riesling. Mild water deficits are normally most beneficial to grape and wine quality. Mild water deficits improved grape quality through higher volatile thiol content in Sauvignon blanc grapes (Peyrot des Gachons *et al.*, 2005). Therefore, this research further supports the importance of vine water status and its impact on aroma potential and sensory qualities of white wine cultivars. Water deficits can reduce berry size and increase the skin to juice ratio (Ojeda *et al.*, 2001). This is important in an aromatic white cultivar such as Riesling where much of their aroma potential is

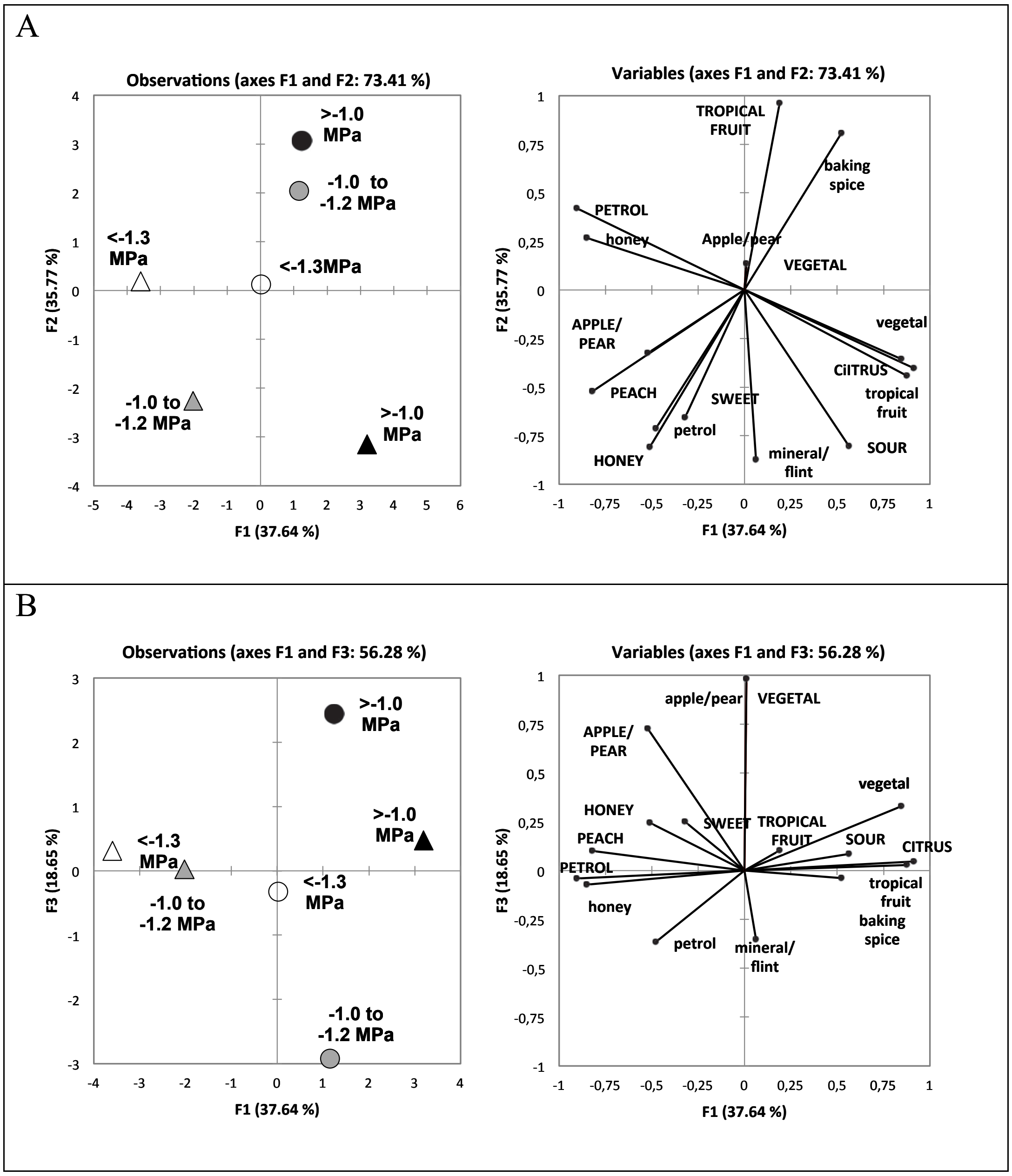

Figure 10. A : Principal component analysis depicting intensity ratings of Riesling wines of different water status categories from within vineyards across the Niagara Peninsula (PC1 vs. PC2). B : Principal component analysis depicting intensity ratings of Riesling wines of different water status categories from within vineyards across the Niagara Peninsula (PC1 vs. PC3). 2005-2006. Legend: ● 2005; ▲2006. Aroma attributes are represented by lowercase and flavor attributes are represented by uppercase.

found in the skins. The increase in fruit-driven aromas may be related to smaller berry weights (Willwerth *et al.*, 2009) and more aroma compounds in the wines since most of them and their precursors reside in the skin (Park *et al.*, 1991). However, once leaf ψ was < -1.3 MPa (showing more water deficit) some of these characters were occasionally decreased, including mineral/flint, tropical fruit, and baking spice, and in the 2005 vintage some vegetative characteristics were highest in some wines. Lack of the fruit character and increased vegetative characteristics could possibly be related to delayed maturity due to an excessively small canopy and poor vine balance as well as delayed maturity. This would have been even more exaggerated due to some winter injury which occurred during the cold 2004/05 winter. Vines may have been struggling as a result of cold related injury and the hot and dry

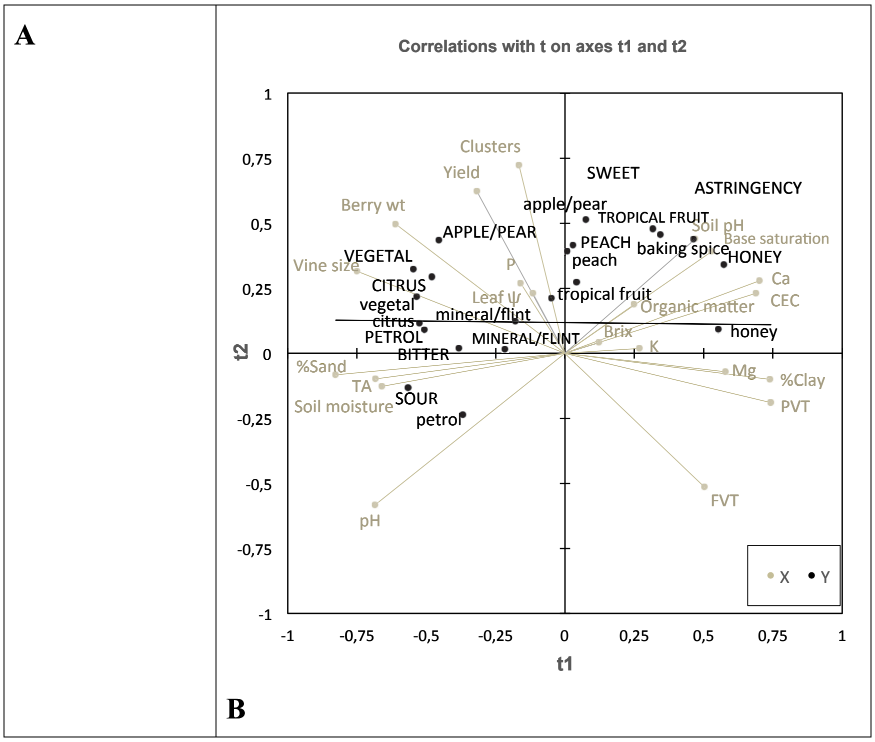

Figure 11. Partial least squares of sensory and vineyard data for Riesling wines of different water status within vineyards across the Niagara Peninsula, 2005 vintage (variance explained in X 43.0%; in Y 25.2%). Aroma attributes are represented by lowercase while flavor and taste/mouthfeel attributes are represented by uppercase. A: Sensory eigenvectors displayed as active variables (X); B: Field and berry composition eigenvectors displayed as active variables (X). Abbreviations: CEC: Cation exchange capacity; FVT: Free volatile terpenes; PVT: Potentially-volatile terpenes; TA: Titratable acidity.

season may have delayed maturity as one of the negative consequences of drought stress demonstrated in the study by Hardie and Considine (1976).

Petrol aroma, which can result in an overpowering bouquet in the wine particularly after bottle age, was also highest in these wines. The responsible aroma compound for the petrol aroma particularly in Riesling is 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN) and is known for its potency with a threshold of 20 µg/L (Simpson, 1978). TDN normally is absent in young wines but develops as a wine ages (Winterhalter, 1991). Many of the vines that had very low leaf ψ were very low in vigor and had high fruit exposure. Grapes exposed to direct sunlight contained more TDN and other norisoprenoids than those shaded (Marais *et al.*, 1992). Therefore, these wines may not age well as they possess some "aged" character to them already. Therefore, it appears that water stress can be both a positive or negative determinant of terroir depending on its severity and timing of onset. It should be noted that no off-flavor comments or descriptors were generated by the sensory panel. Specifically, none of the wines, particularly the low water stress ones had any 'untypical aging off-flavor' (UTA) or 'atypical aging' (ATA) attributes. This off-flavor is characterized by odors of naphthalene, floor polish, wet wool, fusel alcohol or acacia blossom and have been found in Riesling wines from grapes which were grown under water or nitrogen stress (Hoenicke *et al.*, 2002; Rapp *et al.*, 1993).

It appears that there may be a quality threshold for optimum water status that could be potentially elucidated with consumer preference studies. Most importantly, our findings indicate that wines of similar water status had similar sensory characteristics despite vintage to vintage variations and that within a given year wines made from low and high leaf ψ zones within a specific vineyard were distinct from each other. Similar to Matthews *et al.* (1990), wines of different water status had different sensory profiles without many differences in basic fruit composition. This also supports the results/opinions of other authors (Chapman *et al.*, 2005) that Brix, TA and pH are generally arbitrary and not useful predictors to the sensory properties of a wine. Brix values are useful to predict potential

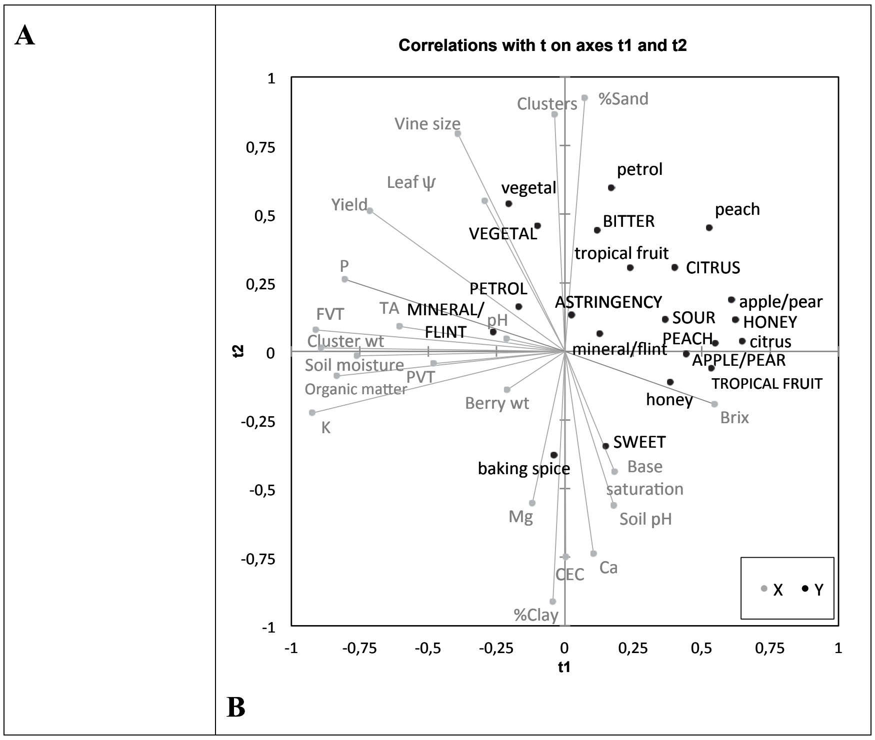

Figure 12. Partial least squares of sensory and vineyard data for Riesling wines of different water status within vineyards across the Niagara Peninsula, 2006 vintage (variance explained in X 54.4%; in Y 22.9%). Aroma attributes are represented by lowercase while flavor and taste/mouthfeel attributes are represented by uppercase. A: Sensory eigenvectors displayed as active variables (X); B: Field and berry composition eigenvectors displayed as active variables (X). Abbreviations: CEC: Cation exchange capacity; FVT: Free volatile terpenes; PVT: Potentially-volatile terpenes; TA: Titratable acidity.

ethanol in the final wine where TA and pH can be useful for winemaking considerations. However, aroma and flavors are not directly related to these variables. This study indicates that vine water status has a strong influence on synthesis or degradation of aroma compounds or their precursors that consequently impact their sensory characteristics.

Conclusions

To our knowledge this is the most extensive study pertaining to the impact of vine water status on white wine sensory attributes and quality. Through sorting tasks and descriptive analysis vine water status had a profound impact on the sensory characteristics of Riesling wines. Consistent leaf ψ zones were found within vineyard blocks and these zones produced wines with different sensory profiles of which several attributes were similar across multiple vineyards across the Niagara Peninsula, Ontario. These differences existed without any vineyard manipulation or cultural practice imposed onto the vines meaning that vine water status is a major factor of the terroir effect. Vines of different leaf ψ produced wines with distinct sensory profiles within vineyard sites but some attributes were site or vintage specific. Since many attributes were similar across vineyards and vintages, examination of leaf ψ ranges of the wines gave a clearer explanation of the impact of water status on their sensory characteristics. Sensory profile differences were found between wines produced with vines that had no water deficit vs. those experiencing mild to moderate water deficits. It does appear that there may be a quality threshold for optimum water status that could be potentially elucidated with consumer preference studies. Sensory attributes differed without differences in terms of basic fruit composition. Therefore, basic fruit composition does not appear to be a useful predictor for Riesling wine quality in the Niagara Peninsula. This is an important finding as many winemakers and growers rely on Brix as an indicator of quality and are paid higher prices according to sugar levels. Ultimately, it can be concluded that moderate water deficit will result in an enhancement in varietal typicity in Riesling wines. Therefore, vine water status could be potentially a positive or negative determinant of terroir and is more than likely one of the largest factors impacting wine quality worldwide, especially with climate change affecting many of the important wine regions.

Acknowledgments

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