IMPACT OF VINE WATER STATUS ON SENSORY ATTRIBUTES OF CABERNET FRANC WINES IN THE NIAGARA PENINSULA OF ONTARIO

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Abstract

Aim: To examine the impact of vine water status on sensory and chemical characteristics of Cabernet franc wines on non-irrigated sites in the Niagara Peninsula, Ontario, to assess whether vine water status might be a key factor in the determination of so-called terroir effects.

Methods and results: The effects of vine water status on wine sensory characteristics were studied in *Vitis vinifera L* cv. Cabernet franc in the Niagara Peninsula (Ontario, Canada) in the 2005 and 2006 vintages. Vine water status was monitored throughout the growing season in ten vineyard blocks using midday leaf water potential (Ψ) values. Chemical and descriptive sensory analyses were performed on nine (2005) and eight (2006) pairs of experimental wines to elucidate differences between wines from high and low water status (HWS, LWS) zones in each vineyard. Twelve trained judges evaluated six aroma, six flavor and three mouthfeel/taste sensory attributes, as well as color intensity. In 2005, LWS wines had higher color intensity (four sites), black cherry flavor (one site), and red fruit aroma and flavor (two sites). Similar trends were observed in the 2006 vintage. No differences were found from one year to the next between the wines produced from the same vineyard, despite markedly different conditions in the 2005 and 2006 vintages.

Conclusions: Measurement of midday leaf Ψ was successful in detecting differences among vine water status levels throughout the growing season. The range of leaf Ψ values were almost consistent at most sites in both 2005 and 2006 years. Differences in vine water status resulted in wines with different composition, aroma, flavor, and color intensity. Despite two different vintages of hot and dry (2005) and wet (2006) seasons, similar trends were observed in high and low water status wines.

Significance and impact of study: The strong relationships between leaf Ψ and sensory attributes of Cabernet franc suggest that vine water status is a major basis for the terroir effect.

Key words: fruit composition, leaf water potential, soil moisture, sensory analysis, anthocyanins, phenols

Résumé

Objectif : Examiner l'impact du statut hydrique de la vigne sur des caractéristiques sensorielles et chimiques des vins de Cabernet franc provenant de sites non-irrigués de la péninsule du Niagara (Ontario) pour évaluer si le statut hydrique de la vigne pourrait être un facteur principal dans la détermination de prétendus effets de terroir.

Méthodes et résultats : Les effets du statut hydrique de la vigne sur des caractéristiques sensorielles de vins ont été étudiés sur *Vitis vinifera L* cv. Cabernet franc dans la péninsule du Niagara (Ontario, Canada) pour les millésimes 2005 et 2006. Le statut hydrique de la vigne a été contrôlé tout au long de la saison dans des blocs délimités sur dix vignobles en utilisant les valeurs du potentiel hydrique foliaire (Ψ). Des analyses chimiques et sensorielles descriptives ont été menées sur neuf (2005) et huit (2006) paires de vins expérimentaux pour élucider les différences entre des vins provenant de zones à haut et bas statut hydrique (HWS, LWS) dans chaque bloc. Douze juges qualifiés ont évalué l'intensité de six aromes et six saveurs et trois attributs sensoriels touchant au goût et aux sensations en bouche, ainsi que l'intensité de la couleur. En 2005, les vins de LWS ont eu une intensité de leur couleur (sur quatre sites), une saveur de cerise noire (sur un site), et des arômes et saveurs de fruits rouges (sur deux sites) plus élevés. On a observé des tendances similaires pour le millésime 2006. Aucune différence n'a été trouvée d'un millésime à l'autre entre les vins produits à partir d'un même vignoble, en dépit de conditions nettement différentes entre les millésimes 2005 et 2006.

Conclusions : La mesure du potentiel hydrique foliaire a permis de détecter avec succès des différences parmi les niveaux de statut hydrique de la vigne tout au long de la saison végétative. L'intervalle des valeurs du potentiel hydrique foliaire était presque régulier sur la plupart des sites en 2005 et 2006. Comme conséquence, les vins ont une composition, des arômes, des saveurs et une intensité de couleur différents. En dépit de deux millésimes très différents : l'un chaud et sec (2005) et l'autre humide (2006), des tendances similaires ont été observées pour les statuts hydriques haut et bas.

Signification et impact de l'étude : Les rapports forts entre le potentiel hydrique foliaire et les attributs sensoriels du Cabernet franc suggèrent que le statut hydrique de la vigne soit une base importante de l'effet du terroir.

Mots clés : composition des fruits, potentiel hydrique foliaire, humidité de sol, analyse sensorielle, anthocyanes, phénols

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INTRODUCTION

Wine water status has long been recognized as an important factor determining winegrape quality and as a consequence affecting wine sensory attributes. Many studies have reported the impact of vine water status in irrigation trials on the accumulation of various grape secondary metabolites such as monoterpenes (Reynolds *et al*., 2006), norisoprenoids (Bindon *et al*., 2007), methoxypyrazines (Sala *et al*., 2005) or miscellaneous aroma compounds and glucoconjugates (Dos Santos *et al*., 2007; Koundouras *et al*., 2006). For red winegrapes, some degree of water deficit during the growing season is considered beneficial for wine quality (Bravdo *et al*., 1985; van Leeuwen and Seguin, 1994; Williams and Matthews, 1990). For example, sensory evaluation on Cabernet franc wines made from four irrigation treatments showed substantial differences in appearance, aroma, and flavor (Matthews *et al*., 1990). Chapman *et al*. (2005) studied the dependence of wine sensory attributes on vine water status in Cabernet-Sauvignon and showed that wines made from a minimally irrigated treatment were significantly higher in red/black cherry, jam/cooked berry, and dried fruit/raisin aromas than their conventionally-irrigated counterparts. Very few studies have investigated the impact of vine water status in non-irrigated situations (Choné *et al*., 2001a,b; van Leeuwen and Seguin, 1994; van Leeuwen *et al*., 2006, 2009). Koundouras *et al*. (2006) investigated the influence of site on grape and wine composition in three non-irrigated sites in *Vitis vinifera L.* cv. Agiorgitiko in southern Greece, and indicated that wines produced from grapes from water-stressed vineyards were preferred sensorially.

Secondary metabolites produced by grapes are the main sources of color, aroma and flavor in wines. Phenolic compounds in the skin play an important role in the quality of red grapes, providing much of the color and structural properties of wines (Ong and Nagel, 1978). In general, a reduction in vine water status reduces vine vigor, and this reduction in vine vigor can concomitantly lead to an increase in berry and wine phenolics (Cortell *et al*., 2005; 2007a; 2007b). A Cabernet franc irrigation study in California showed that the concentrations of organic acids (especially malate), anthocyanins, and total phenolics in grapes at harvest were altered by small changes in vine water status at different phenological stages of vine development (Matthews and Anderson, 1988; Matthews *et al*., 1990). Moreover, Esteban *et al*. (2001) found that vine water status affected the rate of accumulation of phenolic compounds in Tempranillo grapes. Most of these studies have shown a clear and positive effect of imposition of water deficits on berry phenolic analytes. However, few data exist regarding the effect of vine water status on the volatile components of grapes and wines (Bindon *et al*., 2007; Dos Santos *et al*., 2006; Koundouras *et al*., 2006; Reynolds *et al*., 2006).

The goal of this research was to examine the impact of vine water status on sensory and chemical characteristics of Cabernet franc wines on non-irrigated sites in the Niagara Peninsula, Ontario to assess whether vine water status might be a key factor in the determination of so-called terroir effects. Research results describing the impact of site on sensory attributes of Cabernet franc are presented in a companion paper (Hakimi Rezaei and Reynolds, 2010).

MATERIALS AND ANALYTICAL AND EXPERIMENTAL METHODS

1. Vineyard sites

Ten commercial Cabernet franc vineyard blocks were selected for this project in the spring of 2005. Each vineyard block was located in one of the10 sub-appellations of the Niagara Peninsula that had been recently approved by Ontario's Vintners Quality Alliance (VQA). These included: Niagara Lakeshore, St. David's Bench, Creek Shores, Four Mile Creek, Niagara River, Lincoln Lakeshore, Beamsville Bench, Short Hills Bench, Vinemount Ridge, and Twenty Mile Bench (Hakimi Rezaei and Reynolds, 2010).

A grid pattern (8 m x 8 m depending on block configuration) of 75 to 80 sentinel vines was used in each vineyard block for all data collection. Sentinel vines were geolocated using a Raven Invicta 115 global positioning system (GPS; Raven Industries, Sioux Falls, SD) with 1.0 to 1.4 m accuracy. Using Geographic Information Systems (GIS) programs MapInfo and Vertical Mapper (Northwood GeoScience, Ottawa, ON) water status zones were mapped based on vine leaf water potential (Ψ) values. The inverse-distance weighting algorithm was used for creation of the gridfiles and maps. Six leaf Ψ zones with equal magnitude of ranges were created by this process; the two highest and lowest leaf Ψ zones were designated as high water status (HWS) and low water status (LWS) categories, respectively, while the two middle leaf Ψ zones were designated as the medium water status (MWS) category.

2. Vine water status

Midday leaf Ψ was determined between 11 00 h and 16 00 h for fully exposed, mature leaves of similar physiological stage which showed no visible signs of damage and had been in full sunlight. Each leaf sample was covered in a plastic bag and sealed immediately after excision at the petiole to suppress transpiration. The leaf petiole was cut with a sharp razor blade and then inserted into a pressure chamber Model 3005 Plant Water Status

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Console (Soil Moisture Equipment Corp., Santa Barbara, CA) with the cut edge of the petiole facing the outside surface. After sealing the chamber, pressure was increased slowly by opening the compressed nitrogen valve. As soon as sap emerged at the cut end of the petiole, gas flow was stopped and the corresponding pressure was recorded from the gauge, which was in negative bar units (10 bars = 1 MPa). A total of 15 to 20 leaves per vineyard block were used to estimate leaf water potential for each sample date. Overall, there were five sampling dates during the growing season, bi-weekly between late June and early September for each site.

Maps were created each season for each vineyard block to show the separation into the three zones of high, medium, and low water status (HWS, MWS, LWS, respectively) based on the leaf Ψ readings throughout the season. Grapes from each of these water status zones were harvested separately based on the leaf Ψ map for each vineyard block in both 2005 and 2006, and these were ultimately used to make wines. Therefore, from each vineyard block, the three water status designations- HWS, MWS and LWS- were used to make wines in both years. Details of collection of yield components and berry composition are presented elsewhere (Hakimi Rezaei and Reynolds, 2010).

3. Soil water status

Soil moisture data were taken bi-weekly between late June and early September in the 2005 to 2006 growing seasons on five sampling dates. These data were determined using a Fieldscout TDR-300 soil moisture probe (Spectrum Technologies Inc., East Plainfield, IL). Readings (% water by volume) were taken at each of the experimental vines in each block. In total, 72 to 80 vines per site were measured between 08 00 h and 18 00 h. Measurements were taken in the row ca. 10 cm from the base of each vine trunk over a 20 cm depth. It is noteworthy to mention that all vineyards in the Niagara region have tile drains installed at 60 cm depths, and that many of the clay-based soils have very little significant root penetration below 30 cm depth; consequently, the soil moisture measurement depth was considered acceptable. The mean soil moisture at each sentinel vine was calculated from the five separate readings.

4. Origin of wines

Within each vineyard block, high and low water status zones were identified accordingly on the GIS-generated maps. At harvest, fruit from each of the water status zones was hand harvested separately and brought to the Cool Climate Oenology and Viticulture Institute (CCOVI). From each water status zone, three replicate batches (70 to 80 kg fruit) were used to produce wine each year (2005 and 2006). Each replicate represented a sub-zone within each water status zone. Harvest date at each site was based on technological maturity and was mutually determined between the grower, recipient winery, and CCOVI; fruit maturity was comparable between vineyards at harvest.

Grapes from each water status zone from each vineyard block were de-stemmed, crushed and sulfited with potassium metabisulfite (KMS) at 25 mg/L and then inoculated with LALVIN (Selection ICV) 254 *Saccharomyces cerevisiae* yeast (Lallemand Inc., Montreal, QC). All fermentations were carried out in triplicate (based on the field replicates) in 20-L food grade plastic pails, each covered with a lid and air lock. Fermentation proceeded on the skins at 23 °C in an isolated room; with three daily punch downs of the caps for 7 days until dryness. Maceration was allowed to proceed until the caps had fallen for additional 2 days. A bladder press was used to press off the skins to a maximum pressure of 2 bars, and the young wines were transferred into 18-L glass carboys. Wines were kept in -2° C for cold stabilization for 10 days, and afterwards they were racked, sulfited at 25 mg/L and inoculated with *Oenococcus oeni* LALVIN VP41 (Lallemand Inc.) to induce malolactic fermentation, which completed in approximately 4 weeks. Wines were thereafter racked and kept in -2 °C for cold stabilization for a week to precipitate potassium bitartrate from the wine. Following cold stabilization, wines were allowed to warm up to room temperature to prevent excess oxygen pick up by the cold wine and afterwards 50 mg/L KMS was added to all wines, filtered through 1 µ pad filter and 0.45 µ cartridge filter, and then bottled.

5. Chemical analysis

Each wine sample was analyzed for pH via an Accumet pH meter (model 25; Denver Instrument Company, Denver, CO), and titratable acidity (TA) with a PC-Titrate autotitrator (Man-Tech Associates, Guelph, ON) by titration with 0.1 N NaOH to an end point of pH 8.2. Ethanol was determined using an Agilent 6890 series GC system gas chromatograph (Agilent, Wilmington, DE) equipped with an Omegawax 250 fused silica (30.0 m x 250.00 µm x 0.25 µm) column. Other conditions of operation included: carrier gas helium, split ratio of 100.183:1, oven initial temperature 60 ˚C, injection temperature 230˚ C, and detector temperature 225 ˚C. Wine samples or standards were diluted 1:10 with 2 % 1-butanol as internal standard. A 1.0 µL wine sample or standard was injected by an automatic injector and the run time was 5.07 min.

Total phenols, anthocyanins, and color intensity were also determined in wine samples. Total phenols were estimated using standard methods (Slinkard and Singleton 1977). Anthocyanin measurements were performed on

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wine samples using the pH shift method by measuring the differential absorbance at 520 nm between wines at pH 1.0 and pH 4.5 (Mazza *et al*., 1999). Color intensity was determined according to a modified method provided by Mazza *et al*. (1999) with a 12% ethanol solution used as a blank. Color intensity and hue were calculated from absorbance values measured at 420 nm and 520 nm on an Ultrospec 2100 Pro UV/VIS spectrophotometer (Biochrom Ltd., Cambridge, UK).

6. Sensorial analysis

An initial group of 20 judges composed of Brock University faculty, staff, and students were selected for the panel based on their availability and motivation. Six judges were experienced tasters and the others were students with limited wine tasting experience. Eight judges either withdrew or were dropped from the panel by the end of the training sessions. The final panel consisted of five females and seven males whose ages ranged from 22 to 54 years.

Nine (2005) and eight (2006) pairs of HWS/LWS wines were evaluated by 12 judges [(t=18/16, k=8, r=4, b=12), where t, k, r, and b are the number of treatments (wines), number of samples/session, number of replicates and sample sets in each session (or number of panelists), respectively]. At the initial point of training, wine samples were presented to the panel to evaluate and identify relevant aroma, flavor, and mouthfeel attributes. The six experienced tasters individually evaluated these wines and wrote relevant attributes on evaluation sheets. Eight training sessions were thereafter held for all judges. Reference standards were available to define descriptors. In each training session, judges were asked to independently rate the intensity of the descriptive terms in the wine samples as well as standards themselves, and to add terms if necessary. There were also three mouthfeel standards including astringency, bitterness, and acidity to be used for evaluating sample wines (Table 1).

In each training session, three sample wines were served with random codes to all judges to train them to be able to evaluate all wine samples as accurately and consistently as possible. After each training session, data were analyzed to evaluate the performance of each judge. Each attribute was also examined by analysis of variance to find out if that attribute varied across the wine samples and that if the judges were consistent and reproducible.

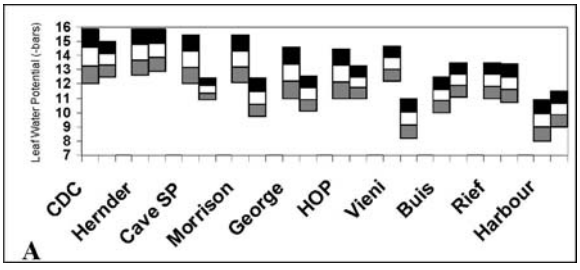
In each session, each judge evaluated eight wines in two flights of four. Judges were given 30-mL wine samples to evaluate in the room temperature (22° C), for the sensory (aroma, flavor, and mouthfeel) attributes. Samples were in 210-mL ISO approved wine glasses and covered with Petri dishes to prevent volatile loss. Glasses were labeled with three-digit random numbers and presented to judges in random order according to the design. All evaluations were conducted using Compusense Five (release 4.8, Compusense Inc., Guelph, ON, Canada) in isolated booths under red light to mask the color differences among wine samples. For color intensity evaluation, 10-mL wine samples were also presented in 5-cm diameter Petri dishes against a white background under natural light, with the same random numbers.

First, the judges evaluated aroma and flavor in the first four wines, and then while they took a short break, evaluated color intensity for the same wines and finished the session by evaluating the second flight of four wines. Evaluation of the magnitude of each attribute was done on a 15-cm unstructured line scale, where 0 and 15 were

Table 1. Aroma, flavor and mouthfeel standards for sensory evalutation of Cabernet franc wine treatments.

Product	Brand	Method of preparation (added to 50 mL of Kressmann red wine unless otherwise indicated)
Strawberry	E.D. Smith strawberry jam	18.6 g jam
Raspberry	Fresh raspberry juice (President's Choice juice box)	4 mL juice
Red fruit	Mixture of E.D. Smith strawberry jam plus fresh raspberry juice	10 mL strawberry std + 10 mL raspberry std
Black cherry	Stewart's black cherry juice	75 mL juice
Black currant	Ribena concentrate	25 mL concentrate
Black pepper	Black pepper	0.5 mL stock
Green bean	Del Monte cut whole green beans	20 mL puree
Bell pepper	Fresh green pepper	1 mL puree
Astringency	Aluminum sulfate (SIGMA)	0.9 g aluminum sulfate in 450 mL water
Bitterness	Quinine sulfate	0.1 g quinine sulfate/L water
Acidity	Tartaric acid	1.5 g tartaric acid/L water
Pectin (for rinsing)	Pectin from apple (SIGMA)	1.25g pectin in 250 mL water

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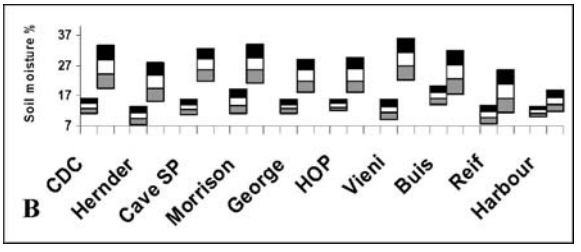


Figure 1A - Midday leaf Y within each of ten vineyard sites (in negative bars), 2005 and 2006, Niagara Peninsula, ON.
Figure 1B - Soil moisture values (%) within each of ten vineyard sites, 2005 and 2006, Niagara Peninsula, ON.
Black, white and gray colors represent low, medium and high water status (A) and high, medium and low soil moisture (B) at each site. CDC, HOP, Cave SP and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively.

anchored with the labels 'absent' and 'high' respectively. Sensory scores were determined by measuring the judges scored mark from the origin in cm. Judges rinsed with water and pectin solution between flavor evaluations in order to prevent carry over effect. Evaluations were started in the morning at 11 00 h and continued until late afternoon to accommodate all judges' schedules. All evaluations were done at Brock University's sensory evaluation room. All wine samples were poured from the same single bottles (750 mL) for duplicates. Aroma standards (Table 1) developed during the training sessions were available to judges prior to each session as reference.

7. Data analysis

Wines from each of high and low water status zone from each vineyard block were subjected to descriptive analysis. A correlation matrix was created on the sensory attributes to illustrate the relationship among variables. Using a t-test, chemical and sensory attributes were compared at each site by means of XLSTAT 2008. Principal components analysis (PCA) was performed using XLSTAT 2008 on the mean sensory scores for the aroma, flavor, and mouthfeel attributes. Partial least squares (PLS) analysis was performed on the field, berry composition and sensory data to ascertain relationships between these data.

RESULTS AND DISCUSSION

1. Grapevine water status

Vine water status varied within all vineyard blocks, enabling a separation of vines into three groups of high, medium and low water status (HWS, MWS, LWS). Leaf Ψ tended to decrease during the growing season as the soil water content decreased and average temperature increased in both the 2005 and 2006 years, and hence minimum values were usually observed at the end of August. Leaf Ψ varied spatially within each vineyard block as well as across vineyard sites. However, the range of leaf Ψ values remained relatively consistent in most vineyard blocks in both years despite different weather conditions (figure 1A). The lowest leaf Ψ values were observed in St. Davids and Virgil at the Chateau des Charmes and Hernder sites in both 2005 and 2006. The Chateau des Charmes site contained poorly-drained clay-based soils (Toledo series; Kingston and Presant, 1989) with shallow rooting depths, while the Hernder site contained Chinguacousy clay loam till that tended to become dry due to high stone content and its free-draining capability. Consequently, water stress was always most apparent at the Chateau des Charmes and Hernder sites, mainly due to shallow vine rooting and high clay content. At Chateau des Charmes leaf Ψ values in HWS categories were -12.0 and -12.5 bars in 2005 and 2006 and ≈ 4 and 2.5 bars less in LWS categories, respectively. Similarly, at the Hernder site, leaf Ψ values in the HWS categories were -12.6 and -12.9 bars in 2005 and 2006 and about 3.3 and 3.1 bars less in LWS categories.

The highest leaf Ψ values were observed at Harbour Estate site in both years such that leaf Ψ values in HWS categories were -8.0 and -9.0 bars in 2005 and 2006, while values of LWS categories were 2.9 and 2.5 bars less than HWS, respectively. Vines at this Ontario Lakeshore site in Jordan did not experience water stress, presumably because of a deep rootsystem and sandy soil (Vittoria series; Kingston and Presant, 1989). Williams and Araujo (2002) reported the Chardonnay vines that received irrigation based on 100% evapotranspiration maintained leaf Ψ values of > - 10 bars, which suggests that vines at the Harbour Estate site were in a high water availability condition similar to that of irrigated vines.

The range of leaf Ψ values at several other sites throughout the region (e.g. George, Cave Spring, Vieni and Morrison sites) were higher in 2006 compared to 2005 due to higher precipitation in 2006 (≈ 120 mm higher in 2006; Grape Growers of Ontario, 2007; figure 2). The 2005 season was a dry and hot year, and water stress appeared earlier and was more severe (figure 2). The leaf Ψ values measured at many of the different sites were consequently in the range commonly reported for non-

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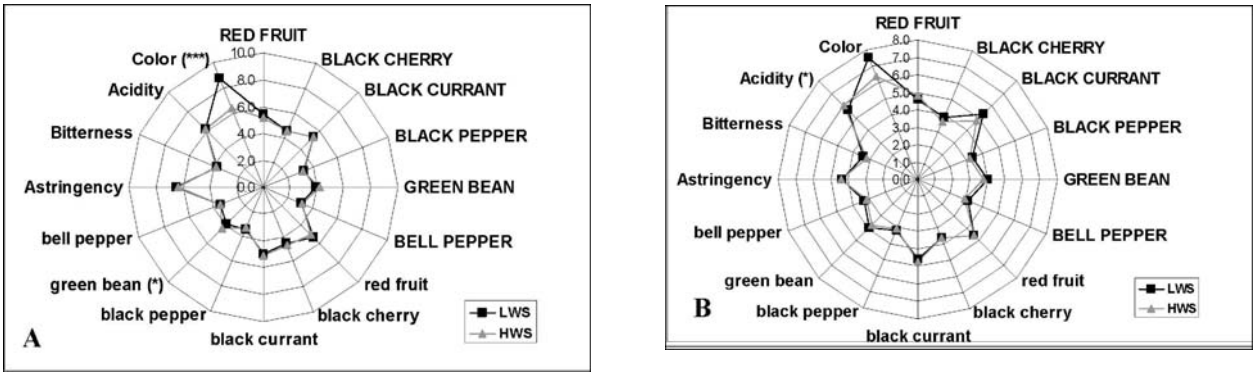


Figure 2 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from the Buis vineyard, Niagara-on-the-Lake, ON, 2005 (A) and 2006 (B).
Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.

irrigated grapevines in California (Williams and Matthews, 1990).

2. Soil moisture

Soil moisture values also varied among vineyards as well as spatially within vineyards in both 2005 and 2006 (figure 1B). The lowest soil moisture values were observed in the Virgil area at the Hernder and Reif sites. At the Hernder site, lowest soil moisture values were 7.3% and 15.1% in 2005 and 2006, and 6.1% and 12.9% higher in high soil moisture areas. Likewise, at the Reif site, low soil moisture values were 7.6% and 11.3% in 2005 and 2006, while values were 6.0% and 14.3% higher in high soil moisture areas. These sites were both characterized by Chinguacousy series clay loam tills (Kingston and Presant, 1989), which permitted free drainage of water due to a high percentage of stone content. The highest soil moisture values in 2005 were in Niagara-on-the-Lake at the Buis site, with a range of 14.0% to 20.4%; in 2006 the highest soil moisture values were observed at the Vieni site (Vinemount Ridge, Campden), with a range of 22.2 % to 35.9%. Both these sites were also characterized by Chinguacousy series clay loam tills (Kingston and Presant, 1989), but with lower stone content compared to the Hernder and Reif locations. Overall, soil moisture values were higher in 2006 at all sites in comparison with 2005 due to higher precipitation in 2006 (figure 1B). High soil water availability reduced vine water stress and increased leaf Ψ values. However, some sites (e.g. Harbour Estate) displayed relatively low soil moisture but had leaf Ψ values that were among the highest. This site contained Vittoria series silt loam (Kingston and Presant, 1989), which permitted deep rooting of vines (and, presumably, the attendant ability to forage for deep water), but had very little water-holding capacity. Conversely, other sites, particularly Chateau des Charmes, had relatively high soil moisture due to the high clay content in the soil (Toledo series lacustrine silty clay; Kingston and Presant, 1989), yet leaf Ψ values were very low due to the shallow rooting depth. Overall, there was a very low correlation between leaf Ψ and soil moisture. Much of the reason was the large variation in soil type, from heavy clays (which limited rooting depth, but retained substantial volumes of water) to coarse sand (which would have permitted deep rooting, reached wilting point in the top 20 to 30 cm, but likely had sufficient water at lower depths). These data from this series of sites underscores the lack of utility of measuring soil moisture, and suggested that midday leaf Ψ was a better indicator of vine water status than soil moisture content.

3. Chemical analysis

a. 2005

Chemical analysis of HWS and LWS wines from 2005 vintage showed that there were no differences between high and low water status wines at three sites (Buis, Chateau des Charmes and Reif); however, some differences were observed at all other sites (Table 2). For example, at the Hernder site, higher pH was detected in LWS wines while at the Harbour Estate site, LWS wines were characterized by lower TA. Anthocyanins and phenols were impacted by water status at several sites. LWS wines were characterized by higher anthocyanins and higher total phenols at the Harbour Estate site, and by higher color intensity at the Cave Spring and Vieni sites. At both Henry of Pelham and Harbour Estate, LWS wines had higher total phenols; pH and ethanol were highest at the Henry of Pelham site in LWS wines (Table 2).

b. 2006

There were no differences between HWS and LWS wines at three sites in 2006 (Buis, Chateau des Charmes, and Morrison; Table 2). However, chemical analysis of high and low water status wines once again illustrated higher pH and lower TA in LWS wines in both Hernder and Reif sites (Table 2). With some exceptions, wines

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Table 2. Chemical analysis of high vs. low water status Cabernet franc wines, Niagara Peninsula, ON, 2005 and 2006.

Site	Hue		Color intensity		Anthocyanins (mg/L)		Phenols (mg/L)		pH		TA (g/L)		Ethanol (% v/v)	
	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS
2005														
Buis	0.63	0.71	7.3	6.2	233	231	2233	2283	3.35	3.36	7.9	8.2	11.8	11.7
Chateau des Charmes	0.73	0.75	7.7	7.2	230	227	1783	1653	3.60	3.65	6.9	6.7	12.6	12.3
Hernder	0.76	0.73	5.2	5.1	267	249	1358	1259	**3.59**	**3.51**	5.9	5.8	11.2	11.1
Reif	0.88	0.82	4.4	4.5	273	264	1450	1446	3.65	3.60	5.8	5.9	11.2	11.0
Harbour Estate	0.83	0.84	4.1	4.0	**285**	**252**	**914**	**819**	3.85	3.79	**5.5**	**5.8**	10.1	10.3
George	0.64	0.59	**5.5**	**6.3**	**281**	**315**	**1459**	**1711**	3.48	3.47	5.7	5.9	10.9	11.2
Cave Spring	0.67	0.63	**7.5**	**6.8**	324	280	1469	1381	3.40	3.41	6.1	6.0	12.4	12.3
Henry of Pelham	0.71	0.67	6.3	6.0	283	267	**1467**	**925**	**3.70**	**3.50**	5.3	5.7	**11.7**	**10.8**
Vieni	0.77	0.80	**4.5**	**4.0**	277	245	1033	825	3.60	3.61	5.5	5.4	10.7	10.4
2006														
Site	**Hue**		**Color intensity**		**Anthocyanins (mg/L)**		**Phenols (mg/L)**		**pH**		**TA (g/L)**		**Ethanol (% v/v)**	
	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS	HWS
Buis	0.58	0.59	5.4	5.9	155	165	836	852	3.50	3.48	6.1	6.4	10.1	9.9
Chateau des Charmes	0.76	0.77	6.8	6.4	136	143	1025	1153	3.65	3.73	6.0	5.9	11.1	11.2
Hernder	0.56	0.52	5.4	5.8	168	155	1092	1230	**3.55**	**3.42**	**5.7**	**6.1**	9.4	0.5
Reif	0.75	0.71	6.1	7.3	155	168	1016	1078	**3.63**	**3.58**	**5.6**	**6.0**	10.8	10.9
George	**0.43**	**0.47**	**8.8**	**6.2**	**257**	**216**	1117	1014	3.31	3.42	7.0	6.4	9.8	9.7
Cave Spring	0.47	0.51	**12.9**	**10.8**	304	278	1345	1089	3.22	3.26	7.1	6.8	12.2	11.4
Henry of Pelham	0.63	0.62	5.8	5.9	186	187	1017	1028	3.43	3.40	6.1	6.6	**8.4**	**9.3**
Morrison	0.78	0.81	4.8	4.6	180	185	1303	1370	3.81	3.80	5.2	5.3	9.2	9.7

from LWS zones tended to be higher in color, with higher concentrations of anthocyanins and phenols than their HWS counterparts. For example, LWS wines were characterized by lower hue (George), higher color intensity (Cave Spring, George) and higher anthocyanins (George). LWS wines at Henry of Pelham had lower ethanol.

Many experiments have assessed the impacts of irrigation on basic wine composition. However, the majority of these have been conducted in arid regions in which irrigation is considered necessary, and only a few have also been done in humid regions that normally receive sufficient precipitation but nonetheless frequently experience droughts. For example, contrary to our results, Freeman *et al*. (1981) increased pH, potassium and TA in irrigated Shiraz, while Freeman and Kliewer (1983) increased wine pH and potassium in irrigated Carignane treatments. Similarly, irrigation > 400 mm annually increased pH and TA and reduced color in Cabernet-Sauvignon (Hepner *et al*., 1985). Much of these adverse impacts of high water status were due to increased crop loads in both Cabernet-Sauvignon and Carignane (Hepner and Bravdo, 1985); consequently, Bravdo *et al*. (1985) exacerbated the negative effects of irrigation on Cabernet-Sauvignon with high crop load treatments. However, Matthews *et al*. (1990) found no consistent irrigation treatment effects on wine pH. More recently, Keller *et al*. (2008) observed that severe irrigation deficits had only minor effects on vegetative growth, yield, fruit composition (soluble solids, TA, pH, potassium, color), and cold hardiness of Cabernet-Sauvignon in Washington.

With respect to phenolic analytes, our results are consistent with Matthews *et al*. (1990), among others, in which higher color intensity and concentration of anthocyanins and total phenols were observed in water deficit treatments compared to continually irrigated vines. Koundouras *et al*. (2006) also reported that early water deficits during the growth period had beneficial effect on the concentration of wine anthocyanins and total phenols in Agiorgitiko. Salon *et al*. (2005) showed that the concentrations of anthocyanins and total phenols in rosé wines, as well as anthocyanins, total phenols and color intensity in red wines significantly decreased with increasing water availability. They also showed that anthocyanins and total phenols were positively correlated with vine water status such that the more negative the leaf Ψ, the higher the anthocyanins and total phenols concentrations.

4. Sensory differences associated with vine water status (see figures 2 to 12)

Sensory evaluation of Cabernet franc wines from LWS and HWS categories showed that differences in vine water status indeed resulted in wines with different composition, appearance, aroma and flavor. At almost all sites in 2005, LWS wines were associated with more fruity, less vegetal character and higher color intensity; however, at each site, specific attributes were significantly different between

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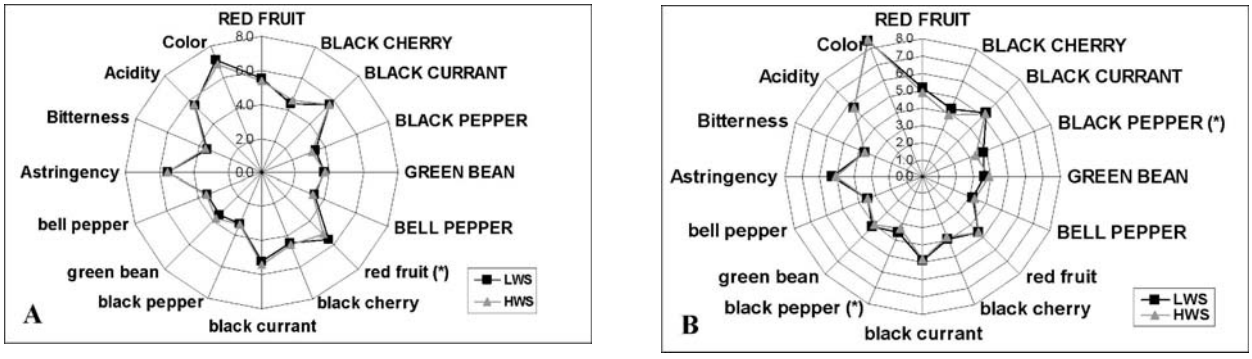


Figure 3 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from the Reif vineyard, Niagara-on-the-Lake, ON, 2005 (A) and 2006 (B).
Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.

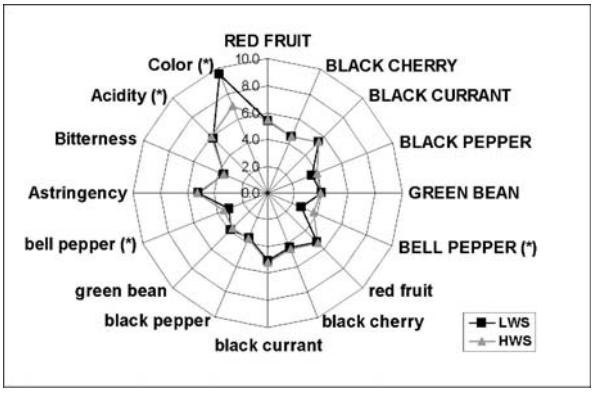


Figure 4 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from Harbour Estate vineyard, Jordan, ON, 2005
Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.

LWS and HWS wines. Comparing high and low water status wines in the 2006 vintage indicated that there were differences between wines at all sites except Henry of Pelham, located on the Short Hills Bench west of St. Catharines.

Vine water status effects were particularly apparent at the several Lakeshore and Niagara River sites. For instance, at the Buis site in 2005, LWS wines showed less green bean flavor and higher color intensity compared with HWS wines (figure 2A), while in 2006, LWS wines had lower acidity (figure 2B). Higher red fruit flavor was detected in LWS wines at Reif in 2005 (figure 3A) but LWS wines in 2006 were high in bell pepper aroma and flavor (figure 3B). At the Harbour Estate site in 2005, there was less bell pepper aroma and flavor in LWS wines as well as lower acidity and higher color intensity (figure 4). At the George site (Lincoln Lakeshore), there were higher red fruit and black currant aromas and higher black pepper flavor in LWS wines in 2005 (figure 5A), while in 2006, LWS wines had higher black cherry, lower black pepper and lower bell pepper aroma, as well as lower black pepper flavor and high color intensity (figure 5B).

Differences between wines from water status zones were also apparent from sites located on the Niagara Escarpment Bench. At Château des Charmes, black cherry flavor was higher in LWS wines in 2005 (figure 6A), while similarly in 2006, LWS wines were characterized with high black cherry aroma, low bell pepper aroma but more bitterness (figure 6B). At the Henry of Pelham site, less black cherry and higher color intensity were observed in LWS wines in 2005 (figure 7A), but no differences were observed in 2006 (figure 7B). At the Morrison site (Jordan Bench) in 2006, higher black cherry aroma, higher bell pepper flavor, lower acidity and higher color were detected in LWS wines (figure 8). At the Cave Spring site (Beamsville Bench) there were no differences between LWS and HWS wines in 2005 (figure 9A), but LWS wines in 2006 had higher black currant and low green bean aromas with higher color intensity (figure 9B).

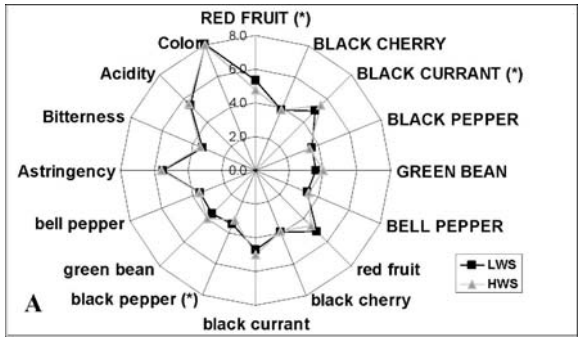
The two remaining sites were Hernder (Four Mile Creek, Virgil) and Vieni (Vinemount Ridge, Campden). At the Hernder site, there were no differences between LWS and HWS wines in 2005 (figure 10A), but in 2006, higher red fruit aroma and flavor was detected in LWS wines (figure 10B). At the Vieni site in 2005, higher color intensity and higher green bean flavor were detected in LWS wines (figure 11).

Overall, low vine water status produced significant sensory aroma and flavor differences in the resultant wines, including increased red and black fruit aroma and flavor, and reduced vegetal character (bell pepper aroma and flavor, green bean aroma and flavor). This is consistent with the results of Koundouras *et al*. (2006) in which they found that limited water availability increased the main aroma compounds of Agiorgitiko grapes, which led to preference of the resultant wines in tasting trials. Dos Santos *et al*. (2007) found that partial rootzone drying of

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Moscatel vines improved berry composition with higher flavour precursor concentrations, without any yield reduction, compared to deficit irrigation and full irrigation. Monoterpenes in Gewurztraminer were increased by irrigation deficits applied at veraison (Reynolds *et al*., 2006). Grape berry carotenoids and C13-norisoprenoid precursors increased in Cabernet-Sauvignon due to partial rootzone drying compared to conventional irrigation (Bindon *et al*., 2007). Few studies exist that have addressed water relations effects on the methoxypyrazine compounds responsible for the green bean and bell pepper aromas. Sala *et al*. (2005) found that irrigated vines and vines planted at a higher plantation density had significantly higher concentrations of isobutylmethoxypyrazine in berry samples than non-irrigated and lower plantation density vines. Overall, these differences in wine sensory attributes due to vine water status suggests a sound basis for managing wine quality in arid areas by deficit irrigation, and in humid non-irrigated areas by site selection with a focus on vine water status.

However, it must be pointed out that most of the research exploring relationships between vine water status and fruit composition, whether conventional aspects such as Brix, TA, or pH, anthocyanins and aroma compounds, or sensory attributes, has taken place within irrigation trials. In such experiments, controlled quantities of water



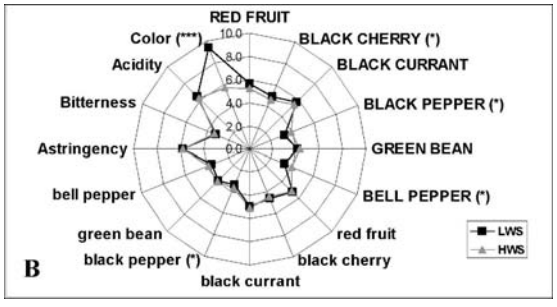
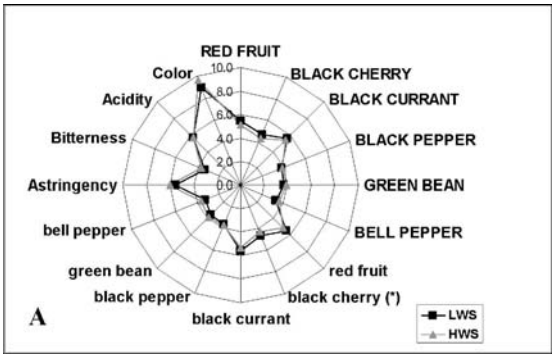


Figure 5 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from George vineyard, Vineland, ON, 2005 (A) and 2006 (B).

Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.



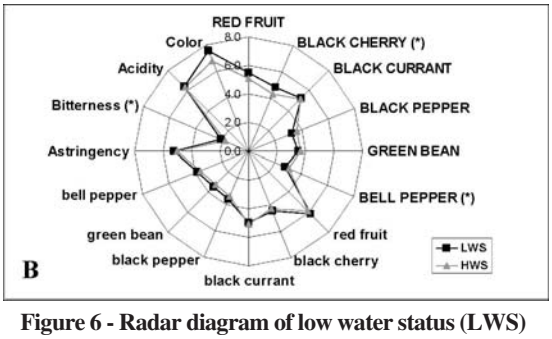
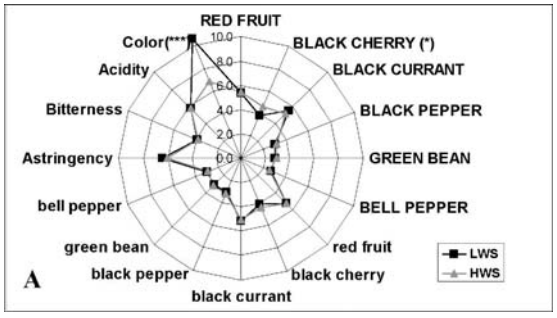


Figure 6 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from the Château des Charmes vineyard, St. Davids, ON, 2005 (A) and 2006 (B).

Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.



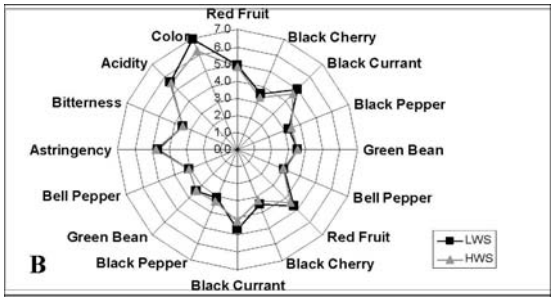


Figure 7 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from Henry of Pelham vineyard, West St. Catherines, ON, 2005 (A) and 2006 (B).

Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.

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were applied and the differences in magnitude between treatments were normally quite large. In our study, the magnitude of differences between water status categories was not known at the initiation of the trial, and the differences between these categories, within specific sites, were often not large.

This approach was essential in order to remove the site climate variable from the experiment, and to instead place the focus upon vine water status. This was attempted by Wahl (1988) by transporting seven soil types of varying water status from throughout Germany to one site in Franken, and planting two cultivars (Müller-Thurgau and Silvaner) in all the soil types. The general conclusion was that soil had minimal impact on berry composition and wine sensory attributes. van Leeuwen *et al*. (2004) investigated impacts of soil type on three red wine cultivars in the Bordeaux region over 5 vintages, and concluded that soluble solids, anthocyanins, and phenols were higher

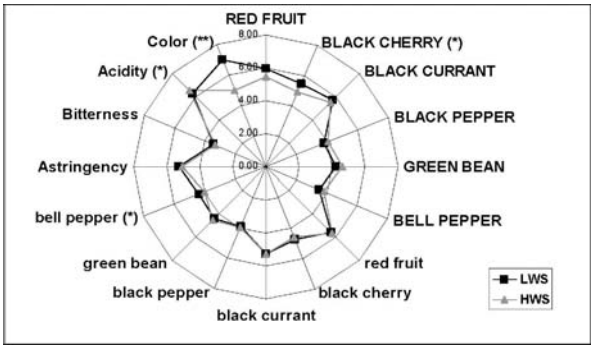


Figure 8 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from Morrison vineyard, Jordan, ON, 2006.
Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.

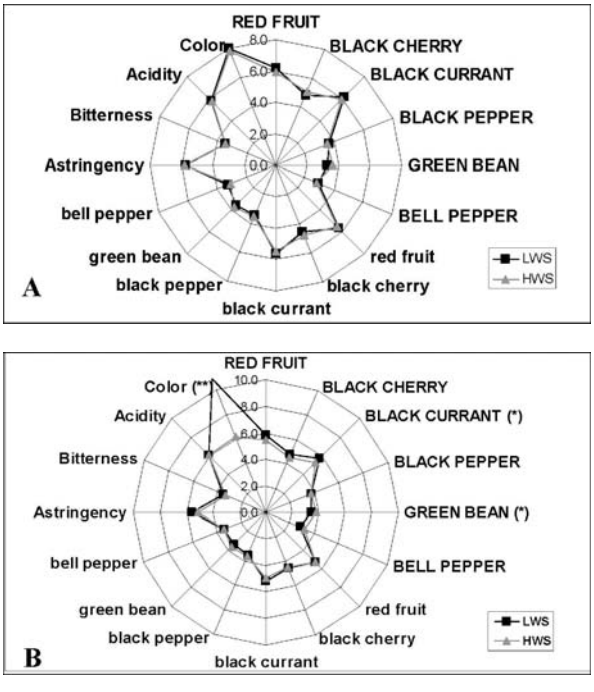
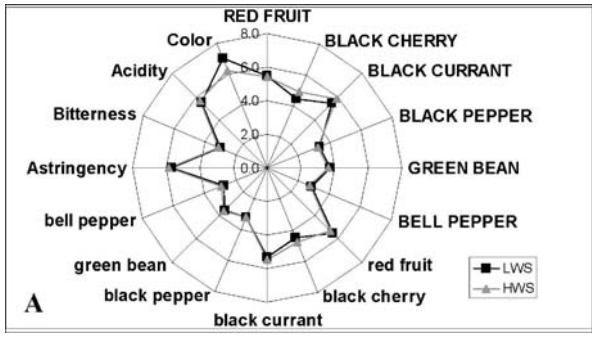


Figure 9 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from Cave Spring vineyard, Beamsville, ON, 2005 (A) and 2006 (B).
Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.



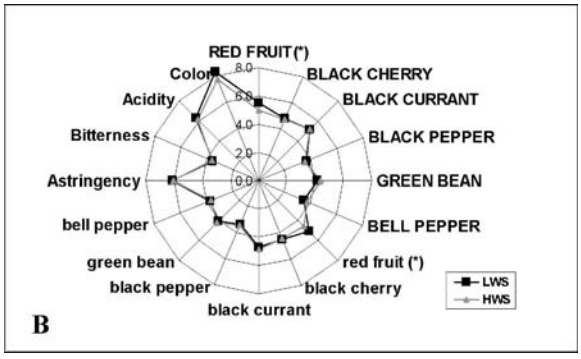


Figure 10 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from Hernder vineyard, Virgil, ON, 2005 (A) and 2006 (B).
Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.

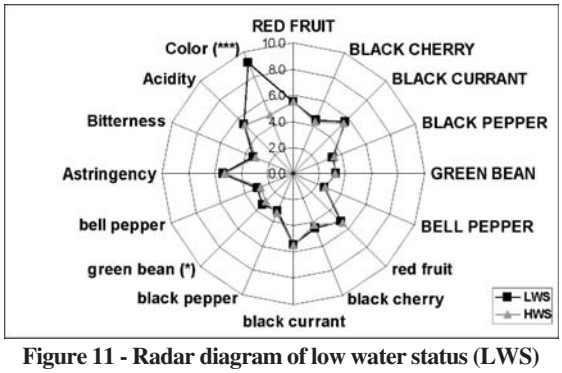
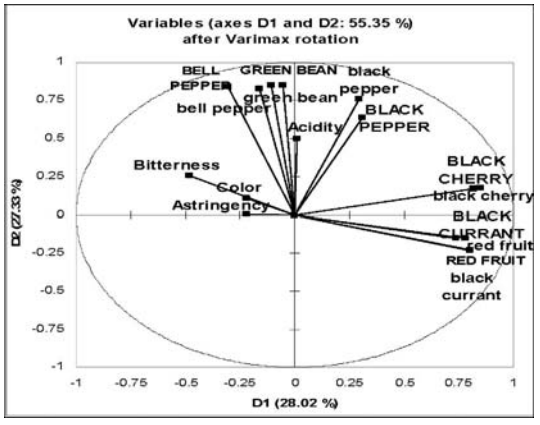


Figure 11 - Radar diagram of low water status (LWS) and high water status (HWS) Cabernet franc wines from Vieni vineyard, Campden, ON, 2005.
Aroma and flavor attributes are specified by uppercase and lowercase letters, respectively.

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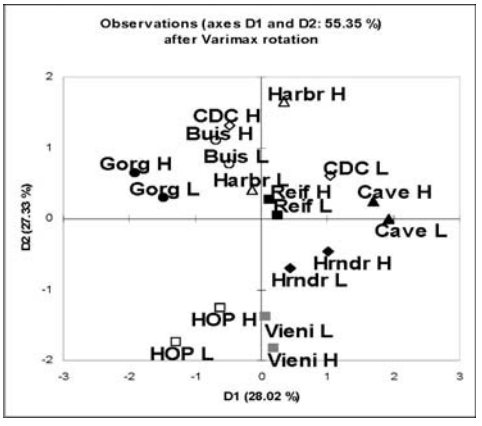


Figure 12 - Principal component analysis (D1 & D2) of mean sensory data for nine pairs of low water status (L) and high water status (H) Cabernet franc wines from the Niagara Peninsula, ON, 2005.

CDC, HOP, Cave, Hrndr and Harbr are abbreviations for Château des Charmes, Henry of Pelham Cave Spring, Hernder and Harbour Estate sites, respectively. Uppercase and lowercase sensory descriptors represent aroma and flavor characteristics, respectively.

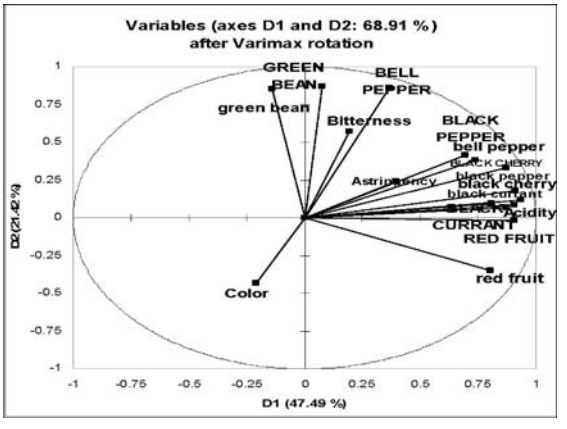
in clay soils than in gravelly and sandy soils. Sandy soils with water tables within reach of the roots encouraged vegetative growth in the vines, and consequently berries were large, malic acid was high, and soluble solids concentrations were low. Although that study involved multiple sites, the actual vineyard blocks were less than 500 m apart in a flat area, therefore site climate can be considered homogeneous among blocks in that study. Similarly, Zamboni *et al*. (2008) showed a strong correlation between soil clay content and anthocyanin concentration in Sangiovese grapes in Emilia-Romagna (Italy).

5. Principal components analysis

a. 2005

PCA was performed on the sensory data in 2005, which showed the relationships between aroma and flavor attributes in nine pairs of high and low water status wines (figure 12). After rotation, PCA explained 55.3% of the variability in the data in the first two dimensions. PC1 accounted for 28.0% of the variability and was most heavily loaded in the positive direction with red fruit, black cherry, and black currant aroma and flavor. PC2 explained 27.3% of the variation in the data set, and was positively loaded with green bean, bell pepper and black pepper aroma and flavor. The third PC explained another 16.6% of variation (data not shown).

Some attributes such as red fruit and black currant aroma and flavor were grouped in the lower right of the plane (figure 12). Black cherry and black pepper aroma and flavor were grouped in the upper right quadrant. Bell pepper and green bean aroma and flavor were grouped with color intensity, astringency and bitterness in the upper left of the plane. Aroma attributes were in almost every case highly correlated with their corresponding flavor attributes. Red fruit and black currant aroma and flavor were negatively correlated with bell pepper and green bean aroma and flavor. Overall, all fruity attributes were highly positively loaded on PC1 and negatively on PC2.



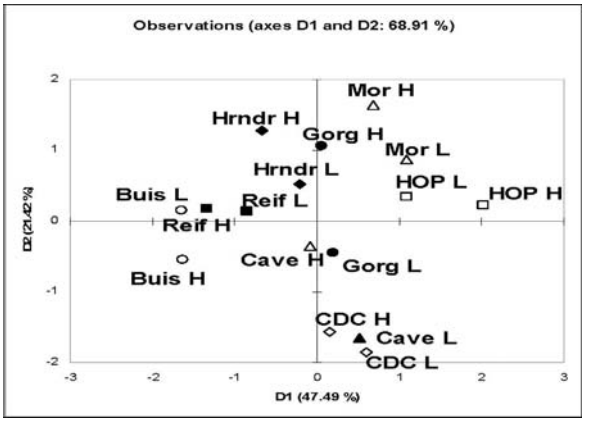


Figure 13 - Principal component analysis (D1 & D2) of mean sensory data for eight pairs of low water status (L) and high water status (H) Cabernet franc wines from the Niagara Peninsula, ON, 2006.

CDC, HOP, Cave, Gorg,Hrndr and Mor are abbreviations for Château des Charmes, Henry of Pelham Cave Spring, George, Hernder and Morrison sites, respectively. Uppercase and lowercase sensory descriptors represent aroma and flavor characteristics, respectively.

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Five sites and their water status zones [Vieni (HWS, LWS), Hernder (HWS, LWS), Cave Spring (HWS, LWS), Reif (HWS, LWS) and Chateau des Charmes (LWS only)] were all on the right hand side of the plane and were explained with red and black fruit aroma and flavor. Four other sites and their water status zones [George (HWS, LWS), Buis (HWS, LWS), Harbour Estate (LWS only) and Chateau des Charmes (HWS only)] were on upper left side of the plane and were explained by bell pepper and green bean aroma and flavor as well as bitterness. Three of these four sites were Lakeshore sites. It was noteworthy that most of the LWS wines were located on the right hand side of the plane and were explained by red and black fruit aroma/flavor. There was also a reasonably good separation of HWS and LWS wines at each site (figure 12).

b. 2006

The relationships between aroma and flavor attributes in eight pairs of high and low water status Cabernet franc wines in 2006 were likewise illustrated by PCA (figure 13). After rotation PCA explained 68.9% of the variability in the data set in the first two dimensions. PC1 explained 47.5% of the variability and was most heavily loaded in a positive direction with red fruit, black cherry, black currant, black pepper aroma and flavor as well as bell pepper flavor and acidity. PC2 explained 21.4% of the variation in the data set, and was positively loaded with green bean aroma and flavor as well as bell pepper aroma and bitterness (figure 13). The third PC explained another 10.8% of variation (data not shown).

Red fruit aroma and flavor were positively correlated in the lower right hand side of the plane. Some attributes such as black pepper aroma and flavor, black cherry aroma and flavor, black currant aroma and flavor, and to a lesser degree bell pepper flavor and astringency were positively correlated and grouped together in the upper right of the plane. Green bean aroma and flavor, bell pepper aroma and bitterness were also positively correlated and grouped together (figure 14). Again, in most cases, aromas of each attribute were highly positively correlated with flavor descriptors. Overall, all fruity attributes were highly positively loaded on PC1 and negatively on PC2.

LWS zones at three sites [Chateau des Charmes (both LWS, HWS), Cave Spring (LWS), and George (LWS)] were associated with red fruit aroma and flavor. LWS zones at two other sites [Henry of Pelham (both LWS, HWS) and Morrison (LWS)] were associated with black cherry, black currant and black pepper aroma and flavor. On the other hand, HWS zones at three sites [Morrison (HWS), George (HWS) and Hernder (both LWS, HWS)] were explained by green bean aroma and flavor and bell pepper flavor. Two other sites [Reif (a Niagara River site; LWS, HWS) as well as Buis (a Lake Ontario site; LWS)

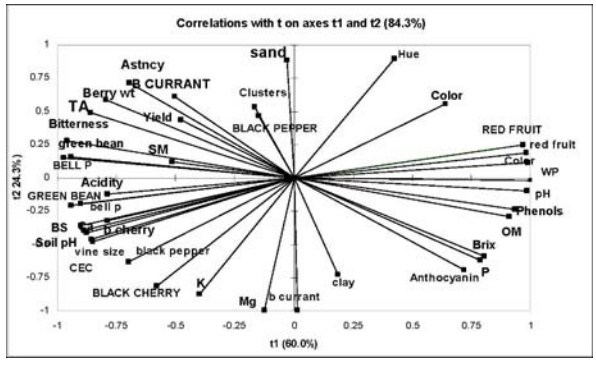


Figure 14 - Partial least squares analysis of field and sensory data for nine Cabernet franc wines from Niagara Peninsula, ON, 2005.

Abbreviations: WP, SM, OM, TA, Berry wt, BELL P, B CHERRY and B CURRANT = leaf Ψ, soil moisture, organic matter, titratable acidity, berry weight, bell pepper, black cherry and black currant aromas, respectively. Uppercase and lowercase sensory descriptors represent aroma and flavor characteristics, respectively.

were explained by green bean flavor (figure 14). Generally, most of the LWS wines were located on the right hand side of the plane and were explained by red and black fruit aroma/flavor. Overall, there was good separation of HWS and LWS wines at each site (figure 14).

Descriptive analysis of Cabernet franc wines produced a contrast between HWS and LWS wines that was based primarily on fruity vs. vegetal descriptors. This is in agreement with a Chapman *et al*. (2005) study in which they found the same trend in Cabernet-Sauvignon, whereby wines made from minimal irrigation treatments were characterized with higher red and black fruity aroma and flavor than wines from conventionally-irrigated treatments. In our current study, most of the variability in wine sensory perception was explained by differences in vegetal vs. fruity attributes. On almost all sites, LWS wines had the lower rating for bell pepper and green bean aromas and flavors, and had the higher rating for red and black fruit aromas and flavors. Our findings are also consistent with those of Matthews *et al*. (1990), who compared early and late-season water deficits with continual irrigation, and reported that continually-irrigated wines differed from wines produced from early and late season water deficits, and, that early season water deficit wines differed from late season water deficit wines in appearance, aroma and flavor.

Once again, the aforementioned studies focused upon water status effects on wine sensory attributes have mostly involved irrigation treatments. Few studies have attempted to prioritize natural water-holding capacity of the soils and its impact on wine sensory attributes. Duteau *et al*. (1981) concluded that St. Emilion and Pomerol (Bordeaux) soils with high gravel content led to mild vine water stress, which consequently resulted in higher soluble

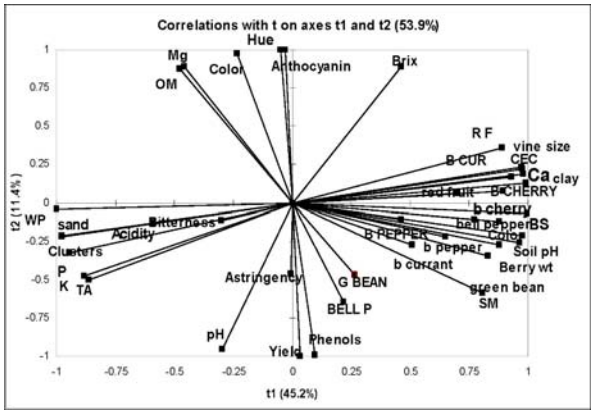


Figure 15 - Partial least squares analysis of field and sensory data for eight Cabernet franc wines from Niagara Peninsula, ON, 2006.

Abbreviations: WP, SM, OM, TA, Berry wt, BELL P, G BEAN, R F, B CHERRY, B CUR and B PEPPER = leaf Ψ, soil moisture, organic matter, titratable acidity, berry weight, bell pepper, green bean, red fruit, black cherry, black currant aromas and bell pepper aormas, respectively. Uppercase and lowercase sensory descriptors represent aroma and flavor characteristics, respectively.

solids, lower malic acid, higher anthocyanins and phenols, and ultimately higher quality wines. Noble *et al*. (1995) found that the most fruity Cabernet-Sauvignon wines were associated with soils with low water holding capacities, whereas wines with vegetal characters were associated with soils with high water holding capacities. However, water status of the vines was not measured in that study, so it was not clear whether the differences in soil texture had any influence on vine water status. In the case of white wine cultivars (e.g. Sauvignon blanc), it is widely recognized that substantial water stress will lead to diminished aroma potential, including a reduction in thiol concentration in the wines (Peyrot des Gachons *et al*., 2005).

6. Partial least squares analysis

PLS was performed on the whole data set in 2005 and 2006 to show relationships among yield components, fruit composition, vine size, soil attributes and water relations with sensory data. In 2005, PLS explained 84.3% of the variability in the data set (figure 14). It illustrated that leaf Ψ was positively correlated with red fruit aroma/flavor, berry pH, berry color intensity, wine color intensity, total phenols and Brix, while negatively correlated with soil moisture, green bean aroma/flavor as well as bell pepper aroma/flavor. Vine size was positively correlated with bell pepper flavor, green been aroma and acidity. Soil moisture was positively correlated with acidity, bitterness, vine size, bell pepper aroma/flavor, green bean aroma/flavor and black cherry aroma and flavor. Clay was positively correlated with black currant and black pepper flavor. PLS analysis in 2006 explained 53.9% of the variation in data set and indicated that soil moisture was positively correlated with green bean aroma/flavor, bell pepper aroma, yield and total phenols. Clay also was positively correlated with red fruit aroma and flavor, black currant aroma and black cherry flavor (figure 15).

Studies involving large data sets focused on intra-block variation in vineyards are somewhat rare. A related study of 10 Riesling vineyard sites suggested that zones of low water status led to increased monoterpenes in the berries (Reynolds *et al*., 2009). Zones of variable water status appeared to be stable temporally, as did the regions of high berry terpenes. In the Rheingau (Germany), sensory properties of Riesling wines were equally influenced by vineyard designation (origin), vintage and wine estate (Fischer *et al*., 1999). Bramley (2005) and Bramley and Hamilton (2004) likewise found that yield and vigor zones within Australian vineyards were stable temporally. Other studies, however, have shown that although variables such as vine vigor remain stable temporally, frequently spatial patterns in fruit composition are transient (Reynolds *et al*., 2007, 2009). These latter situations may be attributed to vintage effects (van Leeuwen *et al*., 2004).

CONCLUSION

Measurement of midday leaf Ψ in this study was successful in detecting differences among vine water status levels throughout the growing season. The range of leaf Ψ values were almost consistent at most sites in both 2005 and 2006 years. Differences in vine water status resulted in wines with different composition, aroma, flavor, and color intensity. Almost at all sites LWS wines were associated with high red fruit aroma and flavor, black fruit aroma and flavor, berry and wine color intensity, total phenols, anthocyanins and berry pH. Despite two different vintages of hot and dry (2005) and wet (2006) seasons, similar trends were observed in high and low water status wines. PLS illustrated that leaf Ψ was positively correlated with red fruit aroma/flavor, berry color intensity, wine color intensity, total phenols and Brix, while negatively correlated with soil moisture, green bean aroma/flavor as well as bell pepper aroma/flavor. Under the conditions of this study, the data suggest that midday leaf Ψ would be a better indicator of vine water status than soil moisture content. Therefore, vine water status offers a means by which wine sensory characteristics can be manipulated.

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