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Impacts of natural yield variances on wine composition and sensory attributes of *Vitis vinifera* cvs. Riesling and Cabernet franc

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**Abstract.** Impacts of naturally-varying yields on composition and sensory attributes of Ontario Riesling and Cabernet franc wines were investigated. Sites represented five Vintners Quality Alliance sub-appellations. A grid pattern of sentinel vines was established in each vineyard for data collection. Yields were divided into categories [Low, Medium, High (LY, MY, HY)] at harvest (2010, 2011) and replicate wines were made from each. Wines were subjected to sensory sorting tasks to confirm differences between yield categories and sites, and were thereafter subjected to descriptive analysis. All HY vines had higher clusters/vine, berry weights, and Ravaz Indices. The HY Cabernet franc wines had lower colour, anthocyanins, and phenols. Sensory sorting revealed differences amongst wines, and descriptive analysis demonstrated several aroma/flavour attributes between yield categories. The HY Riesling wines had less fruit and honey and higher mineral and floral attributes, whereas HY Cabernet franc wines displayed higher bell pepper, vegetal, and herbaceous characteristics and less fruit attributes. Riesling wines from Lincoln Lakeshore North and Niagara Lakeshore sub-appellations had higher mineral or vegetal attributes, Four Mile Creek had more apple/pear and St. Davids Bench, Beamsville Bench and Lincoln Lakeshore South displayed higher fruit and citrus. Escarpment Bench and Four Mile Creek Cabernet franc 2010 wines had highest bell pepper aroma, Lincoln Lakeshore North displayed most earthiness, and the Lincoln Lakeshore South had most cooked fruit. In 2011, cooler sites adjacent to Lake Ontario displayed higher vegetal attributes. Zones of differing yields, dependent upon magnitudes of yield differences, can result in substantially different wine sensory properties.

**Key words:** Terroir, berry composition, wine composition, sub-appellations, sensory descriptive analysis

**Introduction**

It has been a belief since the Middle Ages that low-yielding vineyards were associated with high quality wines (Johnson 1989; Matthews 2015). The majority of the literature suggests that both manipulated (Chapman et al. 2004a; Di Profio et al. 2011; Sun et al. 2011) and naturally-varying yield (Bramley and Hamilton 2004; 2007; Reynolds et al. 2007c) will impact wine composition and sensory profiles. Due to the obvious financial incentive associated with high crop yield, it is important to fully understand the influence that varying yield can have on wine sensory characteristics, wine composition and perceived quality. It is also crucial to identify whether there is temporal stability in patterns of yield variability within a vineyard site to designate vineyard blocks and/or maintain vineyard consistency with the use of precision viticulture (Bramley and Proffitt 1999; Bramley and Hamilton 2004; 2007; Reynolds et al. 2007b). Although many studies have assessed effects of imposed crop levels on wine quality by dormant pruning or cluster thinning treatments (Chapman et al. 2004a; Reynolds et al. 2007b; Bowen et al. 2011; Di Profio et al. 2011), few studies have investigated yield differences attributable to vine vigour, soil type, and inter-vine competition by designating different yield zones (Bramley and Proffitt, 1999; Greenspan and O’Donnell 2001; Bramley and Hamilton 2004; Tisseyre et al. 2005; Bramley and Hamilton 2007; Reynolds et al. 2007c).
Because of economic implications of reduced yield and the ultimate goals of increasing wine quality and profitability, effects of crop level management have been extensively investigated (Bravdo et al. 1984; Ough and Nagaoka 1984; Bravdo et al. 1985; Zamboni et al. 1996). Most have studied effects of manipulated yields on grape, must, and wine composition (Guidoni et al. 2002; Chapman et al. 2004a,b; Reynolds et al. 2007a; Bowen et al. 2011; Di Profio et al. 2011). These studies controlled grapevine yields by cultural practices such as cluster thinning, shoot thinning, dormant pruning or a combination of the three. Pre-bloom fruit zone defoliation was tested to reduce berry set, which resulted in higher wine quality than non-defoliated controls (Pallioti et al. 2012). Manipulating crop level by shoot thinning and cluster thinning were investigated on Merlot and Cabernet Sauvignon in British Columbia (Bowen et al. 2011). Crop adjustments affected canopy characteristics, e.g., reducing pruning weight, in Cabernet Sauvignon but had little effect in Merlot. Also, treatments had few and inconsistent effects on berry weight, anthocyanins and phenols. Contradictory results have been reported with respect to berry weight, with some finding increases with lowered crop level (Guidoni et al. 2002; Sun et al. 2011). Lower-yielding vines typically produce grapes with higher anthocyanins and phenols (Guidoni et al. 2002; Di Profio et al. 2011; Sun et al. 2011) but lowering yields often have no effect on wine composition and quality (Sun et al. 2011). Decreases in yield normally result in increases in pH and soluble solids (Brix), and decreases in titratable acidity (TA) (Reynolds et al. 2007b; Di Profio et al. 2011; Preszler et al. 2013).

Although canopy manipulation and pruning are effective in controlling crop level, which may impact composition of must and wine, these differences, depending on their magnitude, often have little to no effect on the perceived sensory or quality properties of the wine (Ough and Nagaoka 1984; Ewart et al. 1985; Meyers et al. 2013). Wines produced from lower-yielding vines have frequently been rated as higher quality than those produced from higher-yielding vines (Cordner and Ough 1978; Bravdo et al. 1984; 1985). Contrary to these findings and traditional beliefs, other studies have found a decrease in wine quality with yield decreases (Zamboni et al. 1996). Wines made from medium crop levels were optimal for wine quality scores (Loinger and Safran 1971). Variability in the findings of studies such as these may be due to the subjective nature and variability in the definition of wine quality. Also variability can be caused by differences by which yield is reported. Crop load (kg fruit/kg cane prunings; Ravaz Index) has more relevance to the effects of yield compared to crop level (kg/vine), as it is a descriptor of balance between yield and vine vigour (Bravdo et al. 1984; 1985; Kliwer and Dokoozlian 2005).

Soluble solids and TA are often the sole measure of grape maturity and quality. However, many secondary metabolites are more direct measurements of potential wine quality. In aromatic white cultivars such as Riesling, monoterpenes have been associated with crop level manipulation and also wine quality. These have been classified as free volatile terpenes (FVT) and potentially volatile terpenes (PVT), the latter of which include mainly glycosidically-conjugated forms (Mateo and Jiménez 2000). Free volatile terpenes, e.g. linalool, geraniol, and nerol contribute directly to the aroma characteristics of wine (Mateo and Jimenez 2000; Reynolds et al. 2007a), while PVT do not contribute directly to wine sensory profiles but may undergo chemical or enzymatic hydrolysis releasing bound monoterpenes to free forms (Reynolds et al. 2007a,b). The effect of yield manipulation on FVT and PVT concentrations has been studied extensively. Both PVT and FVT in Riesling berries were responsive to cluster thinning (McCarthy et al. 1987; Reynolds et al. 1994; Meyers et al. 2013). In most cases PVT and often FVT increased with decreases in yield. Use of fruit zone defoliation led to increases in FVT and PVT in Gewurztraminer (Reynolds and Wardle 1989) and Chardonnay Musqué (Reynolds et al. 2007a), as well as linalool and thiols in...
Sauvignon blanc (Šuklje et al. 2014). In red wine cultivars, anthocyanin and phenol concentrations have been directly related to colour intensity and wine quality (Mazza and Francis 1995). In traditional Bordeaux cultivars such as Cabernet Franc and Cabernet Sauvignon, 2-methoxy-3-isopropylpyrazine (IPMP) and 2-methoxy-3-isobutylyrazine (IBMP) can have a large impact on sensory properties of (Allen et al. 1991; Hashizume and Samuta 1999). They contribute to the vegetative characteristics of wines produced from these cultivars and in relatively large concentrations can become overwhelming, producing a negative effect. Little work has been done on the influence of yields on pyrazine concentrations of grapes and wine. One study showed that as the yield of Cabernet Sauvignon vines increased by pruning manipulation, IBMP concentrations decreased significantly (Chapman et al. 2004a).

Wine quality scales may not be effective in identifying differences in wine that exhibit apparent differences in their sensory profile (Amerine and Roessler 1976). The use of descriptive analysis techniques can be an effective technique to overcome the subjective nature inherent with wine quality ratings by simultaneously evaluating the differences of multiple attributes (Lawless and Heymann 1997). These techniques have shown that lowering yields can reduce vegetative characteristics and increase the fruit characteristics in some red cultivars (Di Profio et al. 2011). However, an inverse relationship was found in other studies due to increased cluster shading associated with crop level reductions (Chapman et al. 2004a). Lowering yields with cluster thinning can increase the length and intensity of a wine’s finish (Di Profio et al. 2011). Furthermore, similar studies have shown little to no differences in the wine’s sensory attributes (Reynolds et al. 2007b; Sun et al. 2011; Preszler et al. 2013).

Yield can be highly variable, varying as much as 10-fold within a single vineyard block as a result of inter-vine differences resulting from e.g. winter injury, virus infection, and drainage problems, with relatively high temporal stability in the spatial variability (Bramley and Hamilton 2004; 2007; Acevedo-Opazo et al. 2008). In some situations, yield spatial distribution patterns may also vary temporally (Reynolds et al. 2007c). If spatial variability in yield is temporally stable, it may be possible to designate sections of a vineyard block based on yield to produce wines of different styles. It may also be possible to adapt certain cultural practices through the use of precision agriculture to achieve vineyard and fruit consistency. It is first important to understand the relationship between yield variability and berry composition/sensory differences to determine if it is beneficial to either manipulate yield by implementing different cultural practices or designate vineyard sub-blocks to be harvested separately. Geomatic tools such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) integrate information with data collected on vineyard characteristics and delineate vineyard zones based on yield variability to examine relationships between physical and chemical aspects of the vineyard location as well as the effects on grape composition and wine sensory attributes. For example, Cabernet Sauvignon wines with different volatile compound compositions were made from different vineyard sections that were designated based on relatively stable yield differences (Bramley et al. 2011). Wines made from low yielding zones of the vineyard had higher concentrations of volatile compounds associated with fruity characteristics. They also determined that wines made from high- and low-yielding zones differed significantly in sensory attributes. Low yielding zones were more often associated with more fruit characteristics and high yielding zones had higher green and meaty intensities. Low yielding sections of Cabernet Sauvignon and Ruby Cabernet vineyards produced wines with higher colour intensities and phenolic concentrations although yield did not correspond to differences in Brix or TA in some cases (Bramley 2005).

Higher yielding sections of Shiraz and Cabernet Sauvignon vineyards produced grapes that were lower in maturity...
and in phenols (Bramley and Hamilton 2007). Wines produced from low yielding Cabernet Sauvignon sections also had higher ratings for spice, tobacco and pepper flavours compared to high yielding zones characterized with more earthy aromas and less intense aftertaste. However, in another study differences in yield were small and did not correlate with other spatial variables (Trought and Bramley 2011).

The objectives of this research were: i) To assess the impacts of naturally-varying yields on wine composition, specifically pH, titratable acidity, phenols and colour; and ii) To assess impacts of naturally-varying yield on sensory profiles of Riesling and Cabernet franc wines in Ontario. It was hypothesized that wines made from naturally-varying yields would differ substantially in their chemical composition and sensory profiles. This research also had a secondary objective to further validate the Vintners Quality Alliance of Ontario (VQAO) sub-appellations (Fig. S1) in terms of wine composition and sensory attributes. The VQAO is the governing body in Ontario that regulates standards for regional wines. The VQAO created ten sub-appellations within the Niagara Peninsula in 2005 (Shaw 2005; VQAO 2016) based upon a combination of mesoclimate, topography, proximity to Lake Ontario and the Niagara Escarpment, and predominant soil series (Kingston and Presant 1989), but have never been validated statistically or sensorially.

Materials and Methods

In 2010 six Riesling and five Cabernet franc vineyards were selected in the Niagara Peninsula, Ontario, Canada. Sites were chosen based on their locations in each of five VQAO sub-appellations. A grid pattern was developed for each vineyard block with a sentinel vine selected for data collection at each grid intersection (72-84 sentinel vines per site; Jasinski 2013). Cultural practices, including pruning and canopy management were consistent throughout each vineyard. Descriptions of trellis type, number of sentinel vines, vineyard location and soil profiles are available in Table S1 (Riesling) and Table S2 (Cabernet franc).

Harvest and vine size

All vineyards were harvested in 2010 and 2011 in cooperation with the vineyard managers. Harvest dates and Brix at harvest for each site are in Table S3. Grapes were hand-harvested from each sentinel vine with yield and clusters per vine recorded. Yield categories were then created relative to each site whereby vine yields were divided into categories of low, medium, and high yield (hereinafter HY, MY, LY), to provide similar grape volumes for each category constituting the upper, middle, and lower 33% of the overall yield range for each vineyard. From these categories, three replicates were fashioned such that there were three LY, MY, and HY replicates based upon dividing the sentinel vines into three groups spatially in either a N/S or E/W direction perpendicular to the rows. Individual bins (yield category x replicate) were then consolidated and set aside for winemaking. At least 20 kg were available for each replicate. Mean yields for each category are found in Table 1-2 (Riesling) and Table 3-4 (Cabernet franc). During the dormant period, all sentinel vines were pruned and weight of cane prunings (vine size) data were collected from each vine using a fish scale.

Winemaking

Riesling

After harvest, grapes were immediately de-stemmed and crushed at Brock University’s winery. Must was sulphited to 50 mg L\(^{-1}\) SO\(_2\) using potassium metabisulfite (KMS), and 0.04 mL kg\(^{-1}\) must of Cinn-Free enzyme
(Scott Laboratories, CA) was added. The must was cold soaked at 4 °C for 24 h before being pressed at 0.2 mPa for 2 min using an Idropress “50” bladder press (Enoagricola Rossi, Calzolaro, PG, Italy). The juice was allowed to settle for 48 h and racked into three equal-volume fermentation replicates based upon the field replicates into 11-L glass carboys, and 100 mg N L⁻¹ was added using diammonium phosphate (DAP). Each replicate was inoculated with 250 mg L⁻¹ commercial yeast Saccharomyces cerevisiae R-HST (Lallemand, St. Simon, France) following manufacturer’s recommendations. After inoculation, carboys were transferred to a 15 °C chamber until fermentation was completed to dryness. Wines were allowed to settle, racked to clean carboys, and sulphited to 50 mg L⁻¹ SO₂. Carboys were thereafter transferred into a -4 °C chamber for cold stabilization prior to bottling. Wines were analyzed for residual sugar (Zoecklein et al. 1989), and sucrose was added to 18 g L⁻¹ residual sugar. Free SO₂ was analyzed and KMS was added to maintain a free molecular SO₂ level of 0.8 mg L⁻¹ consistent with Margalit (2004).

Following fermentation, wines were filtered with a 0.45 µm membrane filter and bottled into green glass bottles under a screw cap closure. Wines were stored at Brock University’s Cool Climate Oenology and Viticulture Institute (CCOVI) wine cellar at 15 °C and 70% relative humidity until compositional and sensory analysis.

**Cabernet franc**

After harvest, individual field replicates were crushed and de-stemmed to provide three fermentation replicates of 12 L to 18 L of must for each yield category replicate. Additions to musts prior to inoculation included 400 mg L⁻¹ DAP, 50 mg L⁻¹ SO₂, and 0.1 mL kg⁻¹ must of ColorPro enzyme (Scott Laboratories, Petaluma, CA). Each yield category replicate was thereafter inoculated 24 h after harvest with 0.25 g L⁻¹ of commercial yeast S. cerevisiae D-21 (Lallemand, St Simon, France). Fermentations were carried out to dryness at 22 °C in 20-L food-grade plastic pails fitted with fermentation locks. The caps were punched down twice daily, during which soluble solids and temperatures were monitored. After the fermentation was completed each wine was pressed to 0.2 mPa using the aforementioned press. Wines were then racked into 11-L carboys and given 24 to 48 h of settling, after which they were inoculated with 10 mg L⁻¹ of MBR-31 Oenococcus oeni (Lallemand, St. Simon, France) to initiate malo-lactic fermentation (MLF). All wines were kept at 23 °C in a CO₂ environment until MLF completion was determined by paper chromatography. Wines were then moved to a -4 °C room for cold stabilization for up to 2 months. The wines were thereafter sulphited to 0.8 mg L⁻¹ free molecular SO₂ and filtered through a 0.45 µm membrane filter prior to bottling. All wines were thereafter treated as with Riesling wines.

**Analysis for titratable acidity, pH, ethanol**

Wine samples were added to 50-mL beakers and pH was measured by pH meter (Accumet Model 25; Denver Instrument Co., Denver, CO). Titratable acidity (TA) was measured with an autotitrator (PC-Titrator; Man-Tech Associates, Guelph, ON) by titration with 0.1N NaOH to a pH 8.2 end point. Ethanol concentration (2011 only) was measured with a gas chromatograph equipped with a flame ionization detector (Agilent 6890, Wilmintong, Denmark) and a capillary column (Agilent 122-7032 DB-Wax, 30 m length x 250 µm diameter, film thickness 0.25 µm) based on the method of Nurgel et al. (2004). An internal standard was prepared with 0.5 mL of 99.4% 1-butanol in 500 mL of distilled water. Samples were prepared in duplicate by mixing 50 µL of wine with 950 µL of 1-butanol solution. Instrument conditions were: Helium carrier gas flow rate 179 mL min⁻¹; initial oven temperature 60 °C; final temperature 280 °C; run time 4.46 min. A standard calibration curve using the reference factor (area of ethanol peak/area of internal standard peak) was created to determine ethanol concentration.
Analysis for colour intensity, anthocyanins and phenols (Cabernet franc)

The colour intensity/hue analysis was based on Mazza et al. (1999) with minor modifications. All samples were prepared and measured in duplicate and diluted by adding 1 mL of wine to 9 mL of pH 3.5 buffer. Sample absorbance was measured at 420 nm and 520 nm using a spectrophotometer (Ultrospec 2100 Pro UV/VIS; Biochrom, Cambridge, UK) in 10-mm plastic cuvettes. The blank was a solution containing 12% ethanol and 10 g L\(^{-1}\) tartaric acid. Colour intensity was calculated as \( A_{420} + A_{520} \) and hue was calculated as \( A_{420}/A_{520} \). Total anthocyanins were determined consistent with the pH shift method of Fuleki and Francis (1968). Each sample was prepared and measured in duplicate. Buffers (pH 1.0 and 4.5) were prepared as follows: pH 1.0 buffer = 0.2 M KCl + 1 M HCl in distilled H\(_2\)O; pH 4.5 buffer = 1 M sodium acetate + 1 M HCl in distilled H\(_2\)O. Wine samples were diluted by 1:9 (wine to buffer) with each buffer. Samples were then vortexed and allowed to equilibrate for 1 h in the dark at room temperature. Absorbances were read at 520 nm using a spectrophotometer (Ultrospec 2100 Pro UV/VIS), using the appropriate buffer as a blank. Total anthocyanins were calculated as malvidin chloride 3-glucoside equivalents using: total anthocyanins (mg L\(^{-1}\)) = \((A_{520} \text{pH 1.0} - A_{520} \text{pH 4.5}) \times 255.75\).

Total phenols were determined using a modification (Waterhouse 2001) of the method of Singleton and Rossi (1965). All samples and calibration solutions were prepared and run in duplicate. A stock solution of 5 g L\(^{-1}\) gallic acid was prepared by dissolving 0.50 g of anhydrous gallic acid in 100 mL of 10% ethanol. A serial dilution was performed to create 0, 50, 100, 250, and 500 mg L\(^{-1}\) standards used for the calibration curve. All wine samples were diluted 1:9 using distilled water. Wine samples (20 µL) and the calibration solutions were pipetted into 1 cm plastic cuvettes followed by 1.58 mL of distilled water and 100 µL of Folin-Ciocalteu reagent. Mixtures were vortexed, and allowed to stand for 1-8 min at 20 °C. Thereafter, 300 µL of 250 g L\(^{-1}\) sodium carbonate solution was added to each cuvette, then vortexed. Cuvettes were placed in the dark and the reaction was allowed to reach completion after 2 h. Absorbances of the calibration solutions and wine samples were taken at 765 nm against the blank (0 mL calibration solution) using a spectrophotometer (Ultrospec 2100 Pro UV/VIS). Total phenols were calculated in gallic acid equivalents and adjusted for dilution by a factor of 10.

Analysis for methoxypyrazines

Samples of all fermentation replicates from bottled 2010 HY and LY Cabernet franc wines were analyzed for three methoxypyrazines [isopropyl methoxypyrazine (IPMP); sec-butyl methoxypyrazine (SBMP); isobutyl methoxypyrazine (IBMP)] by the solid phase microextraction GC-MS procedure described in Botezatu et al. (2014), using the same instrument described in the method.

Sensory analysis

Sensory analysis was conducted to evaluate differences in sensory profiles of both Riesling and Cabernet franc wines made from grapes of naturally-varying yields growing in different sub-appellations. A two-step strategy was applied in the process of sensory analysis. A sorting sensory task was initially conducted on a large number of wines with a panel experienced in evaluating experimental wines. This is often performed prior to sensory descriptive analysis to ascertain whether descriptive analysis is justified. Thereafter, descriptive sensory analysis was conducted on all wine samples with a trained panel.
**Sorting tasks: 2010**

Multidimensional sorting (MDS) tasks (Abdi et al. 2007; Lelièvre et al. 2008) were performed on Riesling and Cabernet franc wines by a panel of 12 experienced panelists composed of students and faculty of Brock University in a controlled environment, to determine whether there were detectable sensory differences between naturally-varying yield levels within individual vineyards and between sites. Dissimilarity matrices were prepared by recording grouping results from all panelists, i.e. the number of times two particular wines were sorted into the same group. Matrices were then analyzed with XLStat 2010. In the first sorting task, panelists were presented with one HY and one LY wine from each site (Riesling: six sites × two yield categories = 12 samples; Cabernet franc: five sites × two replicates = 10 samples). In the second sorting task, panelists were presented with all three fermentation replicates of HY and LY wines (six samples) from each vineyard site, and this exercise was repeated for each site. For all sorting tasks, 30-mL wine samples were presented all at once in a randomized order in 210-mL transparent ISO glasses coded with three-digit numbers. Panelists assessed all samples based on aroma, retronasal, and basic taste characteristics. Panelists were asked to group those wine samples together that were similar based on their characteristics. No criteria were given other than there must be more than one group and that a single wine may only be used in a single group for each task. Panelists could make as many groups as they liked and were asked to provide descriptors they would use to describe each group. Sorting tasks took place in March 2012 over a two-week period.

**Sorting tasks: 2011**

As in the 2010 wines, 12 experienced panelists composed of students and faculty from CCOVI Brock University participated in sorting tasks. For both cultivars, two sets of sorting tasks were once again carried out. In the first Riesling sorting task, the panelists were presented with two of three replicates of the MY category (M1, M2) from each of five sites (10 wine samples). In the second Riesling sorting, panelists were given three fermentation replicates of HY and LY wines (H1, H2, H3 vs. L1, L2, L3) from each vineyard site. In the first Cabernet franc sorting, three MY fermentation replicates (M1, M2, M3) from each site were presented (15 wine samples). The second Cabernet franc sorting task was performed the same as the second Riesling sorting task. Sample presentation was identical to 2010 wines. Sorting criteria were likewise consistent with 2010 sorting tasks. Sorting tasks were carried out in August 2013 over a two-week period.

**Descriptive analysis 2010**

Descriptive analysis of the Riesling wines was conducted from April to May 2012, and the Cabernet franc wines from June to July 2012. The Riesling panel was comprised of 12 members (five males and seven females), while the Cabernet franc panel had 12 members (six males and six females); all participants were from Brock University (CCOVI), including undergraduate students, graduate students, faculty, and staff, and all had prior experience in sensory analysis. A list of aroma, retronasal, and basic taste descriptors was compiled from the most frequently used descriptors from the aforementioned MDS sessions. Sensory standards (Table S4) were made to represent these attributes and were adjusted over the training period based on panel feedback. During the first training sessions the panelists were presented with a three-sample flight consisting of LY, MY, and HY wines. The panel discussed the provided list of descriptors and sensory standards, and changes were made once consensus was reached. The panel
met for six 60-90 min training sessions during which they were trained on use of a linear scale to describe the intensity of wine attributes.

Data collection took place over a three-week period in May 2012 for Riesling, and in July 2012 for Cabernet franc, at the Brock University sensory laboratory, using Compusense software (Version 5.0; Compusense, Guelph, ON). Nine tasting sessions for the Riesling and eight for the Cabernet franc wines were completed, and each session consisted of two flights of wines presented in random order. For both cultivars, MY wines (M1, M2) from all sites were assessed in the first tasting sessions. Four flights were configured and the first two flights included all M1 wines from the six Riesling and five Cabernet franc sites marked with three-digit numbers and presented in a random order. The third and fourth flights were conducted on all M2 wines with the same procedure as the first two flights. These flights are designed to compare between sites, and it was essential to use fruit representative of each site for this comparison, hence use of MY wines rather than HY and LY wines. Remaining tasting sessions were conducted on HY and LY wines according to site to assess the effect of yield category on sensory attributes. For each site, H1, H2, H3 vs. L1, L2, L3 were evaluated in each of two flights in a random order. A 1-min break was enforced between each wine sample and a 30-min break between each flight. Wines were kept at 18 °C and were presented in ISO glasses. Analysis was conducted in individual booths under red lighting with no time limit. Aroma standards were available to the panelists throughout data collection. Filtered water and unsalted crackers for the Riesling and a pectin rinse for the Cabernet franc were also given to panelists. Each attribute was scored on an unstructured 15-point linear scale (maximum 15 points) with word anchors “absent” and “high intensity.”

**Descriptive analysis 2011**

The panel consisted of 11 panelists (six male, five female) and all the participants were students or faculty members from CCOVI with previous tasting experience. Five, 60-90 min panel training sessions were conducted twice weekly for both Riesling and Cabernet franc wines. Two randomly-chosen wine samples were presented in each training session. An initial list of aroma, flavour, and basic taste descriptors was generated from the most frequently generated descriptors in the MDS analysis. Panel training was conducted exactly as with the previous vintage. Panel training for Riesling was carried out in September 2013 and in October 2013 for Cabernet franc wines. Tasting sessions were thereafter scheduled twice weekly. Tasting conditions and their configuration were consistent with 2010 wines. Lambert Riesling was not available in 2011 due to harvest by the grower prior to data collection. George wines were not available due to insufficient volumes of all yield category replicates.

**Weather conditions**

Weather in 2010 was characterized by normal mean growing season temperatures with normal rainfall in April, May, and July to October (60 mm monthly) but high rainfall in June (130 mm) (Grape Growers of Ontario 2012; Jasinski 2013). Weather during the 2011 growing season was uncharacteristically hot and dry during summer months (50-60 mm rainfall June and July) but cool and wet in April, May, September and October, with 150 mm in May and 125 mm in September (Grape Growers of Ontario 2012; Jasinski 2013).

**Data analysis**

All viticultural variables, wine composition and descriptive analysis data were analyzed with SAS statistical software (V.8; SAS Institute, Cary, NC). The general linear models procedure (Proc GLM) was used for the analysis of variance to demonstrate significance (p ≤ 0.05) amongst viticultural variables (yield/vine, yield/m row,
vine size, Ravaz Index, berry weight, cluster number), wine composition (TA, pH, ethanol, hue, colour intensity, anthocyanins, phenols, methoxypyrazines) and descriptive analysis data. Descriptive analysis used yield category x fermentation replicate x panelist as an estimate of error. Duncan’s multiple range test was used to separate the means at $p \leq 0.05$. These results were also treated using principal component analysis (PCA) using XLSTAT-pro 2010.2.02 (Addinsoft; Paris, France). Sensory data were used as the primary observations and the viticultural variables and wine compositional data as the secondary observations. This treatment of the data allowed correlative relationships between the viticultural variables, wine composition and sensory data to be observed. Difference matrices were constructed from the sensory sorting tasks in Excel files and MDS was run using XLSTAT-pro 2010.2.02 to determine similarities between the yield categories and vineyard sites.

**Results**

**Viticultural variables vs. grape and wine composition**

**Riesling 2010**

Yield categories for all Riesling sites differed in yield/vine and yield/m row (Table 1). The Buis site had the largest difference between HY and LY vines for clusters/vine, the second largest difference in yield, and was the only site to have differences in berry weight and pH, having highest pH values for HY vines. Hughes vineyard had the lowest yield range with LY vines 67% of the HY vines. Relationships between cluster number and yield were observed for every site. The Cave Spring vineyard had the highest ranges of yield/vine and yield/m row, with LY vines 41% of the HY vines. Weight of cane prunings (vine size; an estimate of vine vigor) and Ravaz Indices were not available for the Buis and Lambert sites due to mechanical pre-pruning of the vines prior to intended data collection. Vine size differed for three sites (George, Hughes, Lowrey) between yield categories and ranged from 0.29 kg/m (George LY) to 0.50 kg/m (Hughes HY). According to Shaulis (1980), pruning weight values between 0.36 to 0.4 kg/m are ideal from the standpoint of yield and fruit composition. Ravaz Indices differed for the Cave Spring and George sites with higher values in the HY categories, with overall ranges of 5.6 (Cave Spring LY) to 13.5 (Hughes LY). Few differences between yield categories in terms of TA and pH were observed. Berry composition did not differ substantially between yield categories for individual sites (Table S5).

**Riesling 2011**

Riesling yields and cluster numbers differed between yield categories for all sites (Table 2). The George vineyard had the highest yield range, with LY vines 49% of the HY vines. The Hughes site once again had the lowest yield range, with the LY vines ~ 65% of the HY vines. The Buis, Lowrey, and Cave Spring LY vines were 52%, 55%, and 51% of the HY vines, respectively. Direct correlations between cluster number vs. yield and berry weight vs. yield occurred for each site (Jasinski 2013; Reynolds et al. 2014a). Cluster number differed between yield categories for all sites; Cave Spring had the largest difference and Hughes had the least difference. There were no differences in berry weight between yield categories except the Lowrey site, for which lower yields corresponded with lower berry weights. Vine size varied between yield categories at two sites and ranged from 0.30 (George LY) to 0.56 kg/m row (Cave Spring LY) but vine size and Ravaz Indices were not available for the Buis and Hughes sites due to mechanical pre-pruning. Ravaz Index differed between yield categories for the remaining three vineyards, and in all cases it was highest in either HY or MY categories, with ranges of 4.8 (Cave Spring LY) to
16.8 (George HY). There were no differences between yield categories for pH, TA, and ethanol concentration for three sites (Buis, Lowrey, Cave Spring). For the Hughes site, pH and TA differed between the yield categories, with highest TA in LY wines and highest pH in MY wines, but ethanol was not different (Table 2). For the George site, pH, TA, and ethanol differed between yield categories and MY wines had highest ethanol and pH and lowest TA. As in 2010, berry composition did not differ substantially between yield categories for individual sites (Table S6).

**Cabernet franc 2010**

Yield categories for all sites differed in yield/vine and yield/m row (Table 3). The Buis vineyard had the highest ranges in colour intensity and total phenols and the second largest in yield. The George vineyard had the lowest yield range with the LY vines ≈ 65% of the HY vines; it also had the lowest range in terms of Ravaz Index, berry weight, and cluster number but no difference in vine size. The Kocsis vineyard had the highest range in yield with the LY vines ≈ 32% of the HY vines, and also had highest ranges for vine size and berry weight, but yield categories did not differ in terms of Ravaz Index, TA, pH, hue, and anthocyanins. The HY vines had the highest values for cluster number, berry weight and Ravaz Indices for every site that differed with the exception of Cave Spring berry weight. Vine size ranged from 0.08 (Kocsis LY) to 0.62 kg/m row (Cave Spring HY), with Ravaz Indices ranging from 3.2 (Cave Spring LY) to 14.9 (Kocsis HY). For all sites the LY vines had highest values for all colour and phenolic components with the exception of hue for George wines. Berry composition differed considerably between yield categories, particularly in terms of colour, anthocyanins, and phenols (Table S7).

**Cabernet franc 2011**

There were once again differences within all sites in terms of yield (Table 4). The Kocsis vineyard had the highest yield range with LY vines ≈ 45% of the HY vines. The Cave Spring site had the lowest range of yield with LY vines ≈ 61% of the HY vines. The Buis, Lowrey, and George LY vines were 53%, 57%, and 58% of the HY vines, respectively. Relationships between cluster number vs. yield and berry weight vs. yield were observed for every site, whereby high yields were correlated with high cluster numbers and berry weights (Jasinski 2013; Reynolds et al. 2014b). Cluster number differed between LY, MY, and HY vines for all sites, with the Kocsis site displaying the largest difference and George site having the lowest difference. There were no differences in berry weight between yield categories for the Buis and Lowrey sites. For three sites (George, Kocsis, Cave Spring), berry weight differed between yield categories. For the George and Kocsis sites, lowest berry weight was measured in LY vines, while the relationship in Cave Spring site was reversed. Vine size and Ravaz Index differed between yield categories at all sites, and except for Cave Spring, Ravaz Index was highest in HY and/or MY categories. Vine size ranged from 0.16 (Kocsis MY) to 0.73 kg/m row (Cave Spring HY) while Ravaz Indices ranged from 3.2 (Kocsis LY) to 18.8 (George HY). No wine chemical attribute differed between yield categories for all sites. However, differences occurred for specific sites; between yield categories, TA was lowest in HY for Buis wines; for George, HY wines had lowest TA and highest pH; for Cave Spring, MY wines had lowest anthocyanins and highest hue. For both Buis and George wines, HY wines had lowest TA, while Cave Spring HY wines had highest anthocyanins and lowest hue. Berry composition differed considerably between yield categories, particularly in terms of colour, anthocyanins, and phenols (Table S7).
Sensory sorting

The Kruskal stress value (KSV) was the main criterion to determine separation of wine samples by site or yield category, whereby a KSV ≤ 0.2 is considered acceptable (Abdi et al. 2007; Lelièvre et al. 2008). Two-dimensional scaling (2DS) was in many cases not entirely adequate for site separation with KSVs of 0.26 (Riesling 2010, 2011), 0.22 (Cabernet franc 2010), and 0.25 (Cabernet franc 2011) (Table S8). Three-dimensional scaling (3DS), however, optimized site separation to reduce KSVs to ≤ 0.16.

Riesling sub-appellations

In the sorting tasks where all 2010 Riesling sites were sorted together, 2DS produced a KSV of 0.26, while 3DS reduced the value to 0.16 (Table S8). Distinct clusters were formed between replicates from the Buis, Lambert, Hughes and Cave Spring vineyard sites (Fig. S2A). The George and Lowrey sites did not form obvious clusters. The Lowrey and George H1 samples were not distinguished from the Cave Spring wines. All four samples from Escarpment Bench sites were located to the right, the four Lakeshore samples were situated near the center of the diagram, and the four Lake Plain samples were located in the lower left quadrant. In 2011, 2DS produced a KSV of 0.26 while 3DS reduced the value to 0.13 (Table S8). Only the Hughes wines emerged into a distinct cluster (Fig. S2B). However, three of four Lakeshore wines were located in the lower right quadrant, whereas all Escarpment Bench wines were situated to the left.

Riesling yield categories

Use of 2DS was sufficient to represent the 2010 wine sorting data for Buis, Lambert, Hughes, and Cave Spring sites with KSVs ≤ 0.16 (Table S8; Fig. 1). In two sites (Lambert, Hughes), yield categories were readily separated into two groups by 2DS based on HY and LY levels (Fig. 1B, E). Other sites had KSVs < 0.20 using 2DS, and HY and LY clusters could be readily visualized for Buis, Lowrey, and George sites (Fig. 1A, C, D), whereas Cave Spring could not be as readily sorted, although two replicates of each category appeared separate from the others (Fig. 1F). Use of 3DS on Buis, Lowrey, and George data revealed HY and LY categories, although one Buis replicate (H1) was an outlier (data not shown). For the Lowrey vineyard all three of the LY replicates were clustered but the HY wines did not form a distinct cluster (data not shown). In 2011 (Fig. 2), KSVs were < 0.20 for 2DS for all but the Cave Spring site. Discrete yield category-based clusters were apparent for the Buis (Fig. 2A) and Cave Spring (Fig. 2E) sites. For Lowrey (Fig. 2B), George (Fig. 2C), and Hughes (Fig. 2D) sites, two of three replicates were separated into groups based on HY and LY categories.

Cabernet franc sub-appellations

In the 2010 sorting task, the KSV was 0.22 using 2DS and was reduced to 0.13 with 3DS (Table S8). Buis wines were located in the upper two quadrants and George wines were placed in the two right quadrants (Fig. S3A). Lowrey and Kocsis wines were clustered; the Cave Spring HY wines were grouped with the Buis wines and the LY wines were more closely grouped with the George wines. In 2011, KSVs were 0.25 and 0.15 in 2DS and 3DS, respectively (Table S8, Fig. S3B). Buis, Kocsis, and Cave Spring wines emerged into distinguishable clusters. No distinct groups were formed by the Lowrey and George wines. Lowrey M1 was more closely grouped with two replicates from George site and Lowrey M2 was closely grouped with M3 from the George site.
**Cabernet franc yield categories**

In 2010 2DS KSVs were \( \leq 0.16 \) for four of five sites and 0.18 for the George site (Table S8). For two sites (Buis, Kocsis), yield categories were clearly separated into two groups based on HY and LY levels (Fig. 3A, D). No defined clusters were formed from Lowrey wines (Fig. 3B). A group formed between all three George LY replicates (Fig. 3C) but no distinguishable group was formed between the HY replicates. No defined clusters were formed with 2DS for the Cave Spring wines (Fig. 3E). In 2011, 2DS KSVs were \( \leq 0.15 \) for four of five sites and 0.18 for the Lowrey site (Table 5, Fig. 4). Buis wines clearly formed two groups based on HY and LY categories (Fig. 4A). For Lowrey (Fig. 4B), George (Fig. 4C), Kocsis (Fig. 4D), and Cave Spring (Fig. 4E) sites, two of three replicates formed two visibly distinguished groups based on HY and LY categories.

**Descriptive analysis**

**Riesling sub-appellations**

The 2010 Riesling wine sensory analysis indicated that vineyard location impacted wine sensory profiles (Table 5). Differences were observed for 14 of 20 orthonasal (aroma), retronasal (flavour), or taste attributes. The Buis site had lowest mean scores for seven of 14 sensory attributes (more than any other site) including tropical and apple/pear aromas, and sweet, tropical, peach/apricot, and apple/pear flavours. Buis wines also had the highest scores for mineral aroma and flavour and acidity. Hughes wines had highest scores for more attributes than all other sites including floral, tropical, peach/apricot, and citrus aromas, and floral, peach/apricot and tropical flavours (seven of 14), and also had lowest scores for five of 14 attributes including mineral and apple/pear aromas, mineral and apple/pear flavours, and acidity. The 2011 Riesling wines were noticeably different in terms of aroma and flavour characteristics between vineyard sites (Table 5). Differences were found in seven of 20 attributes (peach/apricot, citrus, vegetative aroma; citrus and honey flavour, sweetness and acidity) across all five sites. Buis wines had highest scores for peach/apricot aroma, citrus flavour and acidity and lowest for honey flavour and sweetness. George wines had the highest vegetative aroma and sweetness and the lowest peach/apricot aroma and citrus flavour. Hughes wines had highest citrus aroma and honey flavour and lowest vegetative aroma. Lowrey wines had the lowest citrus aroma and acidity. The Cave Spring site was noteworthy in that no highest or lowest scores were detected for the seven sensory attributes with differences across the sites.

**Riesling yield categories**

The 2010 HY and LY Riesling wine sensory analysis for each individual site indicated that yield category impacted wine aroma and flavour attributes (Fig. 5). Differences were found in 13 of 20 attributes for one or more of the sites. The most common attribute to differ was mineral aroma, with differences in three vineyard sites, followed by honey aroma, tropical fruit and apple/pear flavours, which differed for two sites. The Lowrey site had the most attributes that differed between yield categories (eight) (Fig. 5C), followed by Hughes with three (Fig. 5E), Buis (Fig. 5A), Lambert (Fig. 5B), and George (Fig. 5D) with two, and Cave Spring wines with one attribute that differed (Fig. 5F). The 2011 HY and LY wine sensory analysis within each site (Fig. 6) suggested that yield category did not have as large an impact sensorially as in 2010. In all 20 attributes, only four differed. For Buis (Fig. 6A) and Lowrey (Fig. 6B) wines, each site had one attribute that differed, which were peach/apricot and honey aromas, respectively. The Hughes site (Fig. 6D) had no attributes with differences between HY and LY levels. The Cave Spring site (Fig. 6E) had the most attributes with differences (vegetative aroma, length of finish).
**Cabernet franc sub-appellations**

The 2010 Cabernet franc wine sensory analysis indicated that vineyard location had an impact on wine sensory profiles (Table 6). Differences were observed for six of 18 attributes. The Cave Spring site had highest scores for three of six attributes, more than any other site, including red fruit and earthy aromas, and red fruit flavour, and was also the only site that did not have the lowest score for any of the attributes. The Buis and Lowrey sites had the lowest scores for three attributes: red fruit, earthy, bell pepper aromas (Buis), and red fruit aroma, cooked/dried fruit aroma, and red fruit flavour (Lowrey). Both Buis and Lowrey sites had the highest scores for one attribute each: spicy flavour (Buis) and bell pepper aroma (Lowrey). The George and Kocsis sites had the highest and lowest scores for two attributes. The 2011 wine sensory analysis showed that vineyard location impacted 16 of 19 wine aroma and flavour/taste/mouthfeel attributes across all sites (Table 6). Buis wines had highest scores for bell pepper aroma and spice flavour and lowest scores for dark fruit aroma and dried fruit flavour. Lowrey wines had highest scores for dried fruit and herbaceous flavour and lowest scores sites for red fruit, dark fruit, bell pepper, and spice aromas; red fruit, dark fruit, and spice flavours, and astringency. George wines had highest scores for red fruit aroma and flavour, bell pepper flavour, and acidity, and lowest scores for dark fruit aroma and flavour. Kocsis wines had the highest scores for two attributes (dried fruit and earthy aroma), and had the lowest scores for dark fruit aroma, acidity, body, and length of finish. Cave Spring wines had the greatest number of highest mean scores (seven of 16 descriptors), including dark fruit and spice aroma, dark fruit and spice flavour, astringency, body, and length of finish, and also had lowest scores for earthy aroma and bell pepper and herbaceous flavour.

**Cabernet franc yield categories**

The 2010 HY and LY Cabernet franc wine sensory analysis within each site indicated that yield category had a significant impact on wine sensory profiles (Fig. 7). Differences were found in nine of 18 descriptors for one or more of the sites. Astringency and dark fruit flavour differed between yield categories for two of five sites. Bell pepper, dark fruit, cooked/dried fruit aromas; spice, bell pepper, cooked/dried fruit flavours, and length of finish differed between yield categories for at least one of the sites. Kocsis wines (Fig. 7D) possessed the most sensory attributes that differed between HY and LY wines with five, followed by the Buis, Lowrey, and George vineyard sites with three, two and one attribute(s), respectively (Fig. 7A, B, C). There were no differences between yield categories for the Cave Spring site (Fig. 7E). The 2011 HY and LY wine sensory analysis within each site (Fig. 8) indicated that yield category impacted 17 of 19 aroma and flavour characteristics. Buis wines had the most attributes with differences between the HY and LY levels with 14 attributes including red fruit, dark fruit, vegetal, herbaceous, spice, and earthy aroma; red fruit, dark fruit, bell pepper, and herbaceous flavour; astringency, acidity, body, and length of finish (Fig. 8A). Lowrey (Fig. 8B) and George wines (Fig. 8C) each had three of 17 attributes with differences between HY and LY categories; these were: red fruit aroma, spicy flavour, bitterness (Lowrey), and bell pepper and vegetal aromas and red fruit flavour (George), respectively. Kocsis (Fig. 8D) and Cave Spring wines (Fig. 8E) each had only one of 17 attributes (spicy flavour and astringency, respectively) with differences between the HY and LY categories.
Principal components analysis

Riesling sub-appellations 2010

Principal component 1 (PC1) and PC2 accounted for 61.0% and 21.1% of variability, respectively, for significant sensory attributes of the MY wines for all sites (Fig. 9). The viticultural variables and wine composition data were plotted as supplementary variables to display their relationship to the sensory attributes. Apple/pear, floral, mineral, peach/apricot, and tropical aroma attributes were strongly correlated with their corresponding flavour attribute, and, citrus, floral, peach/apricot, tropical, and sweetness were associated with yield, cluster number and Ravaz Index. Apple/pear, honey, and mineral, characteristics had an inverse relationship with most yield components. Beamsville Bench (Cave Spring) and Lincoln Lakeshore South (Hughes) sites were associated with higher tropical character, the St. Davids Bench site (Lowrey) was associated with high citrus, floral, sweetness, and peach/apricot characteristics, the Niagara Lakeshore (Buis) and Lincoln Lakeshore North (George) were associated with high minerality and acidity, while the Four Mile Creek (Lambert) site was associated with high apple/pear and honey character.

Riesling sub-appellations 2011

PC1 and PC2 accounted for 46.2% and 23.5% variability, respectively, for sensory attributes of the MY wines for all sites (Fig. 10). The yield component and wine composition data were again plotted as supplementary variables. Mineral and herbaceous aroma attributes were strongly correlated with their corresponding flavour attributes. Apple/pear, floral, honey, and peach/apricot aromas, apple/pear and citrus flavour, and acidity were correlated with all yield components. These were inversely correlated with herbaceous, mineral, and vegetative, characteristics as well as wine pH and alcohol. The Lincoln Lakeshore South and Beamsville Bench sites (upper right quadrant) were dominated by floral and honey aromas and citrus and apple/pear flavours, the Niagara Lakeshore site (lower right quadrant) was dominated by apple/pear and peach/apricot aromas, and acidity. The Lincoln Lakeshore North and St. Davids Bench sites (lower left quadrant) were dominated by vegetative aroma and herbaceous aroma and flavour. The Lincoln Lakeshore North and South sites were not clustered despite close geographic proximity.

Riesling yield categories 2010

PC1 and PC2 accounted for 38.1% and 21.1% of the variability, respectively, for significant sensory attributes of the HY and LY wines for all sites (Fig. 11). Viticultural variables and wine composition data were again plotted as supplementary variables. Apple/pear, floral, honey, mineral and tropical aroma attributes were strongly correlated with their corresponding flavour attribute. Yield components and vine size were inversely correlated to apple/pear, honey, spice, mineral, and tropical attributes as well as length of finish and to some degree directly correlated to floral flavour. Wine pH was inversely related to TA and acidity, and directly correlated with yield components. The Buis, Cave Spring, George, and Lambert HY and LY wines were closely grouped. The HY and LY wines from Hughes and Lowrey sites were substantially separated. The Buis, Hughes and Lambert samples were located right of PC2 and associated with apple/pear, honey, spice, mineral, and tropical attributes as well as length of finish.

Riesling yield categories 2011

PC1 and PC2 accounted for 42.6% and 21.5%, respectively, for sensory attributes of the HY and LY wines for all sites (George site excepted, due to insufficient volumes of HY and LY wines) (Fig. 12). Yield components and wine composition data were again plotted as supplementary variables. Apple/pear, citrus, herbaceous, honey, mineral,
and petrol aroma attributes were strongly correlated with each other and with their corresponding flavour attributes, and vegetative aroma was strongly correlated with herbaceous aroma and flavour attributes, but peach/apricot aroma was strongly inversely correlated with peach/apricot flavour and associated with cluster number. Nearly all sensory variables were correlated to some degree and were likewise correlated to yield. A group of eigenvectors in the upper right quadrant included citrus, herbaceous, mineral, and vegetative, while those in the lower right quadrant included apple/pear, floral, honey, petrol, sweetness, and finish. All HY and LY wines were clustered by site; Cave Spring wines were located in the upper right quadrant, Hughes in the lower right, Lowrey in the lower left, and Buis in the upper left. Cave Spring wines were dominated with citrus, mineral, and herbaceous aromas and flavours as well as peach/apricot flavour and vegetative aroma, Hughes wines with floral aroma, apple/pear, honey, petrol, finish, and sweetness, Lowrey wines with peach/apricot aroma, and Buis wines with low levels of most sensory attributes.

**Cabernet franc sub-appellations 2010**

PC1 and PC2 accounted for 52.8% and 38.3% of variability, respectively, for significant sensory attributes of the MY wines for all sites (Fig. 13). The viticultural variables and wine composition data were plotted as supplementary variables. Red fruit aroma had a positive relationship with its corresponding flavour and was correlated with most yield components, and inversely correlated with spice flavour. Most phenolic and colour components were likewise inversely correlated with most yield components. Berry weight had an inverse relationship with earthy aroma, vine size and cluster number. Ravaz Index was correlated with cooked/dried fruit aroma and inversely related to TA. Lincoln Lakeshore North wines (upper right quadrant) were associated with earthy aroma, Lincoln Lakeshore (South) wines (lower right quadrant) were associated with red fruit characteristics, Four Mile Creek and Beamsville Bench wines (upper left quadrant) were associated with bell pepper aroma and spice flavour, while the St. Davids Bench wines were located at the intersection of PC1 and PC2 and not well characterized.

**Cabernet franc sub-appellations 2011**

PC1 and PC2 accounted for 58.8% and 23.3% of variability, respectively, for all the sensory attributes from the descriptive sensory analysis of the MY wines for all sites (Fig. 14). The vine characteristic and wine composition data were plotted as supplementary variables. Red fruit, dark fruit, dried/cooked fruit, and bell pepper aroma and flavour were strongly correlated with their corresponding flavour attributes. All phenolic analytes, including anthocyanins, total phenols and colour intensity, were strongly correlated with astringency. Yield components were strongly correlated with TA and acidity, as well as red fruit, spice, and finish. The Four Mile Creek wines (upper right quadrant) were associated with vegetal aroma and herbaceous flavour, Lincoln Lakeshore South and St. David’s Bench wines (lower right quadrant) were associated with earthy and herbaceous aromas, dried/cooked fruit aroma and flavour, and bitterness, Beamsville Bench wines (lower left quadrant) were associated with dark fruit aroma and flavour and phenolic components, whereas the Lincoln Lakeshore North wines (upper left quadrant) were associated with bell pepper and red fruit aroma and flavour.

**Cabernet franc yield categories 2010**

PC1 and PC2 accounted for 33.8% and 27.8% of variability, respectively for significant sensory attributes of the HY and LY wines for all sites (Fig. 15). The viticultural variables and wine composition data were plotted as supplementary variables. Bell pepper, cooked/dried fruit and dark fruit aroma attributes were strongly correlated
with their corresponding flavour attribute. Bell pepper characteristics were inversely correlated with astringency, colour and phenolic components, length of finish and cooked fruit characters and correlated with vine size and yield components. Dark fruit characteristics and spice flavour were inversely correlated with berry weight. All LY wines with the exception of Cave Spring were located right of PC2 and therefore associated with cooked fruit, dark fruit, spice flavour, astringency, and phenolic analytes. The HY wines were predominantly located left of PC2 except George vineyard and associated with bell pepper characteristics. Cave Spring, Lowrey, and George wines were closely associated. HY and LY wines from Buis and Kocsis vineyards were well-separated.

**Cabernet franc yield categories 2011**

PC1 and PC2 accounted for 50.6% and 20.2%, respectively, for all sensory attributes of the HY and LY wines for all sites (Fig. 16). Yield components and wine composition data were plotted as supplementary variables. Red fruit, dark fruit, dried fruit, spice, bell pepper, and herbaceous aroma were strongly correlated with their corresponding flavour attributes and vegetal aroma was strongly correlated with bell pepper and herbaceous aroma and flavour. Phenolic analytes and ethanol were strongly correlated with each other as well as with dark fruit, dried fruit, red fruit, and spice characteristics, as well as astringency, bitterness, body, and finish, and inversely correlated with most yield components. Acidity was correlated with TA and inversely correlated with bell pepper, earthy, herbaceous and vegetal aromas. Yield components were to a large degree associated with bell pepper, earthy, herbaceous and vegetal characteristics. Four of five LY wines were located right of PC2, and were therefore associated with dark fruit, dried fruit, red fruit, and spice characteristics, as well as astringency, bitterness, body, and finish. Most HY wines were left of PC2 and associated with bell pepper, earthy, herbaceous and vegetal characteristics. Cave Spring and Kocsis wines were clustered in the upper right and upper left quadrants, respectively, while the Buis and Lowrey wines were separated into their HY (upper left quadrant) and LY (lower right quadrant) samples, respectively. George wines likewise were separated, with the HY and LY wines placed in the lower left and lower right quadrants, respectively. Cave Spring wines were most associated with red fruit, dark fruit, dried fruit, and spice characteristics, as well as finish, body, and all phenolic analytes. Kocsis wines and Buis, George and Lowrey HY wines were more associated with bell pepper, earthy, herbaceous, and vegetal characteristics.

**Methoxypyrazines in Cabernet franc**

Crop level, when examined across all sites, decreased Cabernet franc SBMP but slightly increased IBMP (Table 7). With sites taken separately, crop level had no impact on methoxypyrazines in Buis and Lowrey wines, but crop level increased IBMP at the three remaining sites (Table 7). IPMP and SBMP were unresponsive to crop level at all sites. Comparing sites with crop levels pooled, Kocsis produced highest IPMP, Cave Spring had highest SBMP, and Lowrey had highest IBMP (Table 7). Lowest IBMP levels were measured in Buis, George, and Kocsis wines.

**Discussion**

**Effect of naturally-varying yields on viticultural variables**

For all sites, the Riesling and Cabernet franc HY vines had higher cluster numbers than the LY vines. This confirms that cluster number is one of the main determinants of yield. Cluster number can be manipulated by winter pruning (Freeman et al. 1980) and cluster thinning (Di Profio et al. 2011). Pruning was carried out consistently within each site, Riesling was not cluster thinned, and Cabernet franc was cluster thinned by removal of distal
clusters. This suggests that the variance ascribed to cluster number was due primarily to natural causes. Cluster number varies due to bud fruitfulness and the viability of those buds retained at pruning. May and Cellier (1973) expressed potential bud fruitfulness as a combination of percent bud fruitfulness (percent buds with one or more inflorescence primordia), inflorescence primordia per bud (inflorescence primordia in the primary or the secondary buds, or both), and integrated fruitfulness index (sum of the diameters of all inflorescence primordia per bud in mm). Number of inflorescence primordia per bud and their size are developmental factors contributing to crop yield. Variability in bud fruitfulness can be caused by differences in light exposure (Smart et al. 1990), and by differences in temperature (Palma and Jackson 1981), including severe winter temperatures. The weather conditions in the 2010 and 2011 winters were relatively mild, suggesting that winter damage did not play a significant role in yield variability (VQAO 2016).

Berry weight had less association with natural yield variance in Riesling vines than Cabernet franc. Berry weight was only different in two instances for the six Riesling sites over two years. Mean berry weights of the HY vines were higher in five instances for the Cabernet franc sites over two years, but lower for one site in both seasons. Despite the difference in yield variance between the two cultivars, similar trends were observed in the PCA, with berry weight being correlated to yield in most circumstances. Cluster thinning or shoot thinning before bloom typically results in yield compensation in terms of increased berry weight (Reynolds et al. 1994). This study suggests that there was no obvious yield compensation (e.g. increased berry weight) resulting from natural yield variance for both cultivars. A similar study found no difference in berry weight between different yield zones within a single Cabernet Sauvignon block, which are consistent with the trends for the Riesling sites but contradictory to the Cabernet franc results (Bramley et al. 2011). The berry weight differences among Cabernet franc vineyards may be the result of higher vine water status (Jasinski 2013; Reynolds and Hakimi Rezaei 2014; Reynolds et al. 2014a,b). Cabernet franc vines with higher leaf water potential (ψ) had higher yields and berry weights (Reynolds et al. 2014b), and it was therefore highly likely that vine water status was a main factor in yield variability in this study. Related activity in this study showed conclusively that there were spatial differences in every Riesling and Cabernet franc vineyard in soil moisture and leaf ψ, and these were correlated strongly with yield components (Jasinski 2013; Reynolds et al. 2014a,b).

The Ravaz Index ("crop load") is frequently used as an indication of vine balance. Crop loads > 12 produce conspicuous effects of overcropping with reductions in wine quality, colour, aroma intensity, delay of fruit maturation and sugar accumulation (Bravdo et al. 1984; Smart 1985; Kliewer and Dokoozlian 2005), while values < 5 indicate excessive vine vigor. Two Riesling sites (George, Cave Spring) had mean HY values of > 12 in 2010, suggesting overcropping, with all other HY category values > 10. The LY vines at the Hughes site also exceeded 12. None of the Riesling sites had values < 5 in any yield category. In 2011, three sites had HY vines > 12 (Lowrey, George, Cave Spring) and two of these also had MY vines > 12. For the Cabernet franc sites in 2010, the HY and LY vines at the Kocsis site had values of > 12 in 2010, with the HY category having a value > 14. The Kocsis vineyard, although it had the highest differences in yield and berry weight, had no Ravaz Index differences in 2010. This can be explained by the fact that the Kocsis vineyard also had the highest variance in vine size. In 2011, one vineyard (George) had a Ravaz Indices substantially > 12 (18.8 and 17.1, respectively) in the HY and MY vines, while in two situations (Kocsis and Cave Spring LY), Ravaz Indices were < 5. Overall, the Ravaz Indices were different in seven instances based on six Riesling sites over two years and in eight instances based on five Cabernet
Franc sites over two years, with HY categories having the highest values in most cases. In general, despite differences between yield categories, most sites had vines that were in balance with few exceptions. Sites with differences in the Ravaz Index generally had little to no differences in vine size between yield categories.

**Effect of naturally-varying yield on wine composition**

There were no differences in wine TA or pH with the exception of Buis Riesling pH in 2010 and George and Hughes TA and pH in 2011 and George Cabernet franc TA and pH in both seasons. This was contradictory to the findings of similar studies, who found that high yield produced wines with higher TA and pH in Cabernet Sauvignon wines (Bramley et al. 2011) while high vigor zones were associated with higher TA values in Riesling wines (Reynolds et al. 2007c), respectively. The majority of the Cabernet franc sites in 2010 had differences in hue, intensity, total anthocyanins, and total phenols, with higher mean values attributed to the LY category, but there were fewer differences between yield categories in 2011. The findings correspond well with the results from Bramley et al. (2011) but are not completely consistent with trends observed in the berry composition. Differences in berry hue, colour intensity, anthocyanins and total phenols were found in fewer of the sites compared to the wine. It is assumed that the HY vines produced higher berry weights that led to a lower skin:juice ratio, leading to wines with lower concentrations of anthocyanins and phenols. Therefore, it cannot be claimed that naturally-varying yield has an effect on phenolic and anthocyanin biosynthesis or degradation.

**Effect of naturally-varying yield on wine sensory profiles**

The sorting tasks performed in this experiment reduced time and fatigue issues compared to conventional difference testing, while still providing reliable information on differences between wines (Abdi et al. 2007; Lelièvre et al. 2008). The sorting tasks indicated that there were differences of the sensory perception of the wines from naturally-varying yield categories, although for only two of three replicates of the Cave Spring Riesling in 2010 and three sites in 2011. The 2010 Cave Spring Cabernet franc wines could not be separated, and separation of the all replicates of the Lowrey wines (2010) and three sites in 2011 was not successful. This corresponds strongly to the results of the descriptive analysis, which found differences between HY and LY categories in only one attribute for the Cave Spring Riesling (2010), limited differences for all sites in 2011, no difference in the Cave Spring Cabernet franc (2010), and limited differences in 2011.

Descriptive analysis using a trained panel nonetheless provided indications that there were differences amongst wines produced from different yield categories. Panel training that was conducted on the two cultivars assessed eight aroma and 12 flavour attributes for the Riesling wines and seven aroma and 10 flavour attributes for the Cabernet franc wines. Of these, numerous aroma and flavour/taste attributes for the Riesling and three aroma and six flavour/taste/mouthfeel attributes for the Cabernet franc differed amongst the different yield categories.

Although wine sensory differences were found between yield categories for most Riesling sites, the effects varied between sites and seasons. Mineral aroma was the sensory attribute that was most consistently affected by yield variance in 2010, yet it differed in only half of the sites. Only three other attributes had yield category differences common to more than one site including honey aroma and apple/pear and tropical flavour. The Hughes and Lowrey vineyards had the most attributes with differences in 2010, and were the only two vineyards that had HY and LY categories separated in the PCA. The Hughes LY Riesling was associated with more tropical aroma and flavour and the Lowrey LY Riesling with more floral aroma and flavour and less minerality. Effects of yield category on
Cabernet franc wines likewise varied between site and season. In 2010, out of the nine attributes that differed, only three differed for more than one site. Some yield-related differences were noticeable in 2011 especially in wines from the Buis site. Despite these inconsistencies, there was a separation between most 2010 HY and LY wines in the PCA with the exception of George and Cave Spring wines. Buis and George wines were likewise separated in 2011. These results suggest that Cabernet franc wines were more responsive sensorially than Riesling to naturally-varying yield.

Similar results were found in terms of yield component effects of sensory attributes for both Riesling and Cabernet franc wines when evaluating the results of the PCA. For both cultivars, the yield components were frequently more inversely weighted on PC2, with the exception of the Riesling Ravaz Index and vine size. For Riesling the findings suggested that higher yield components such as yield, cluster number and berry weight had less intense aromas and flavours with the exception of floral flavour. Terpenes are one class of odor active compounds found in Riesling berries at harvest (Cordonnier 1956). Lack of differences in FVT and PVT in the berries from different yield categories suggests that there may have been differences in terpene extraction during the winemaking process. Terpene analysis of the wine would be needed in order to confirm these suggestions. For the Cabernet franc, vines with HY, vine size, and cluster number produced wines with higher bell pepper characteristics and lower colour components, total phenols, cooked/dried fruit character and finish. HY wines contained higher IBMP concentrations. The increased bell pepper character coincides with the findings that high-yielding vines had higher IBMP concentrations, which is a major contributor to bell pepper character in wine (Ryona et al. 2010). The degradation of IBMP was apparently hindered enough in HY berries to maintain higher concentrations that were substantial enough to affect the sensory perception of the resulting wines despite the dilution effects of higher berry weight. It is noteworthy that LY vines were concomitantly lower in vine size and likely had higher cluster exposure than HY vines, and this would have led to diminished IBMP concentrations (Chapman et al. 2004a,b). As to site effects, there did not appear to be clear and explainable patterns; the Kocsis site (warm, low vine size, heavy clay) had highest IPMP, Cave Spring (moderate heat units, high vine size, clay loam till) had highest SBMP, and Lowrey (warm, high vine size, clay loam) had highest IBMP. However, Kocsis wines also had lowest IBMP, which may have been attributable to the low yields and the concomitant high fruit exposure (Roujou de Boubée et al. 2000).

**Effect of sub-appellation on wine sensory profiles**

The wine growing regions of the Niagara Peninsula are not homogenous in terms of mesoclimate. Differences in topography, soil type, distances from the lake and escarpment creates large variability in the environment in which grapes are grown (Shaw 2005). The VQAO created ten sub-appellations in the Niagara Peninsula based on soil, climatic and topographical differences. The PCA of the Riesling sensory, viticultural variables, and wine composition data showed that vineyards located on or near the St. Davids (Lake Iroquois) Bench were more closely related sensorially to Beamsville Bench than vineyards located on the nearby Iroquois Plain. The Lincoln Lakeshore (North) and Niagara Lakeshore vineyards were associated with higher mineral, vegetative, and herbaceous characteristics, while the Four Mile Creek and Lincoln Lakeshore (South) vineyards were higher in fruit, floral and citrus characters. The same trend was not seen in the PCA of sensory, viticultural variables, and composition data of Cabernet franc wines. In 2010, both Escarpment Bench vineyards and the Four Mile Creek vineyard were associated with wines high in bell pepper aroma, colour intensity, anthocyanin and phenol concentration. The Lincoln Lakeshore (North) vineyard was associated with more earthy character and higher vine size than the...
Lincoln Lakeshore (South), which was associated with more cooked fruit character and higher Ravaz Index. In 2011, the Beamsville Bench wines were associated with dark fruit and the St Davids Bench and Lincoln Lakeshore (South) with dried fruit, whereas Four Mile Creek and Lincoln Lakeshore wines were characterized by herbaceous and bell pepper characteristics.

**Implications for precision viticulture**

Precision viticulture is a relatively new management technique that focuses on identifying spatial variation of a vineyard block and implementing informed, targeted management regimes based on information gathered (Proffitt *et al.* 2006). It is important to understand the effects of the variability within the vineyard in order to evaluate the degree of positive or negative changes on the outcome of wine quality and ultimately profits. Studies such as this one provide information on the first two steps of precision viticulture and can be used as guiding advice as to what to look for and how to use it. Fig. S4 to S7 show the yield spatial variability within all the vineyard blocks studied. There is also clear indication that spatial variability in yield in the vineyards in this study was related to relevant physiological variables such as soil moisture and leaf $\Psi$, as well as several berry composition variables (Jasinski 2013; Reynolds *et al.* 2014a,b). A similar study conducted in New Zealand showed that the spatial variability is also temporally stable (Bramley and Hamilton 2004). The methods in this study would need to be repeated to confirm that the variability is temporally stable and there effects on sensory profiles remain consistent for these Ontario vineyards. If spatial variability is temporally stable, and spatial relationships between variables are consistent, then the vineyard management or winemaking team can make decisions to substantially influence wine quality, style and profitability. This can be done by specific block designation to implement different cultural practices to improve vineyard consistency or for segmented harvesting.

**Conclusions**

It was hypothesized that wines made from naturally-varying yields would have significant differences in their initial viticultural variables, chemical composition, and sensory profiles. A secondary hypothesis was that wines produced from the VQAO sub-appellations would differ in their chemical composition and sensory attributes. Wines produced from different yield categories differed in: i) viticultural variables (e.g. cluster number, berry weight, vine size, Ravaz Index); ii) chemical composition (e.g. TA, pH, hue, colour intensity, anthocyanins and total phenols), and; iii) sensory aroma and flavour/taste/mouthfeel attributes. The yield level was determined mostly by cluster number. HY vines produced larger berries in five instances for Cabernet franc across five sites and two seasons, but only in two instances for six Riesling sites across two seasons. Vines with higher yields also tended to have higher vine size and Ravaz Indices. Cabernet franc HY wines had in most cases lower colour, anthocyanins and total phenols. Naturally varying yield tended to have little to no effect on pH and TA for both cultivars. Sensory sorting was an effective method in determining the presence of differences amongst wines, and was successful in most cases in demonstrating differences between HY and LY wines. Descriptive analysis provided further specific information on wine sensory profiles. Several aroma and flavour attributes differed between HY and LY wines for both Riesling and Cabernet franc. The effect of naturally-varying yield on Riesling sensory profile was more variable than that of Cabernet franc wines. HY Riesling wines at some sites were associated with less fruit characteristics and more mineral or floral character. HY Cabernet franc wines were associated with higher bell pepper and less fruit characteristics. Sub-appellation likewise had an effect on the wine sensory profile. The Lincoln Lakeshore (South) wines were associated with more cooked fruit character and higher Ravaz Index.
Lakeshore (North) and Niagara Lakeshore Riesling vineyards were associated with higher mineral, herbaceous and vegetative characteristics in both seasons, whereas the Four Mile Creek location had more honey and apple/pear character, and the St. Davids Bench, Beamsville Bench and Lincoln Lakeshore (South) vineyards were higher in fruit and citrus characters. Cabernet franc wines from vineyards located on the Escarpment Bench and the Four Mile Creek vineyard were higher in bell pepper aroma in 2010, while Lincoln Lakeshore (North) vineyard was associated with more earthy character, and the Lincoln Lakeshore (South) was associated with more cooked fruit character. In 2011, Beamsville Bench wines were characterized by dark fruit and St Davids Bench and Lincoln Lakeshore (South) with dried fruit, whereas Four Mile Creek and Lincoln Lakeshore wines were associated with herbaceous and bell pepper characteristics. Information on the consistent effects of natural yield variance could be utilized by precision viticulture management techniques after further study of temporal stability.

**Acknowledgments**

Funding was provided by the Ontario Research Fund. We hereby thank all of the industry partners for allowing this research to be possible. These include: Glenlake Orchards and Vineyards, Cave Spring Cellars, George Vineyard, Hughes Vineyard, Kocsis Vineyard, Lambert Farms, Lowrey Five Rows Craft Winery. The participation of all sensory panelists is hereby acknowledged; without your help and dedication of time this research would not be possible. Acknowledgements are also due to Dr. Helen Fisher for guiding comments and feedback during the first year of the study, and to Dr. James Willwerth for assistance with the sensory design and statistical analysis of the MDS process. We also thank Dr. Andreea Botezatu for assistance with methoxypyrazine measurement.

**Literature Cited**


### Table 1. Impact of crop size on yield components and wine composition of six Riesling vineyards, Niagara Peninsula, Ontario, 2010.

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**Note:** *, **, ***: Significant at p ≤ 0.05, 0.01, 0.001, 0.0001, or not significant, respectively. Mean values are listed followed by different letters are significant at p ≤ 0.05, Duncan’s multiple range test.

<sup>a</sup> Mechanically pre-pruned prior to vine size data collection.

<sup>b</sup> Ravaz Index = Yield / vine size; TA = titratable acidity.
Table 2. Impact of crop size on yield components and wine composition of five Riesling vineyards, Niagara Peninsula, Ontario, 2011.

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<th>Vine size (kg/m row)</th>
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Note: *, **, ***: Significant at p ≤ 0.05, 0.01, 0.001, 0.0001, or not significant, respectively. Means followed by different letters are significant at p ≤ 0.05, Duncan’s multiple range test.

a Mechanically pre-pruned prior to vine size data collection.

b Ravaz Index = Yield / vine size; TA = titratable acidity.
Table 3. Impact of crop size on yield components and wine composition of five Cabernet franc vineyards, Niagara Peninsula, Ontario, 2010.

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Note: *, **, ***; ns: Significant at p ≤ 0.05, 0.01, 0.001, 0.0001, or not significant, respectively. Means followed by different letters are significant at p ≤ 0.05, Duncan’s multiple range test.

* Ravaz Index = Yield / vine size; TA = titratable acidity; Hue = A₄20/A₅20; Colour Intensity = A₄20 + A₅20
Table 4. Impact of crop size on yield components and wine composition of five Cabernet franc vineyards, Niagara Peninsula, Ontario, 2011.

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<th>pH</th>
<th>Hue</th>
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<th>Total phenols (mg L⁻¹)</th>
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<th>Total phenols (mg L⁻¹)</th>
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Note: *, **, ***; ****, ns: Significant at p ≤ 0.05, 0.01, 0.001, 0.0001, or not significant, respectively. Means followed by different letters are significant at p ≤ 0.05, Duncan’s multiple range test.

*Ravaz Index = Yield / vine size; TA = titratable acidity; Hue= A_{420}/A_{520}; Colour Intensity = A_{420}+A_{520}
Table 5. Summary of mean sensory scores determined through comparison of wines from Niagara Peninsula, Ontario Riesling vineyards by descriptive analysis of medium crop size categories, 2010 (six sites) and 2011 (five sites) (n= 12 judges; two fermentation replicates).

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<th>Buis (Niagara Lakeshore)</th>
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<th>Lowrey (St. Davids Bench)</th>
<th>George (Lincoln Lakeshore North)</th>
<th>Hughes (Lincoln Lakeshore South)</th>
<th>Cave Spring (Beamsville Bench)</th>
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<td>3.4b</td>
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Note: *, **, ***: Significant at p ≤ 0.05, 0.01, 0.001, respectively. Means followed by different letters are significant at p ≤ 0.05, Duncan’s multiple range test.

a Petrol aroma and flavour, herbaceous flavour, length, and body were non-significant both seasons and hence are not included.
Table 6. Summary of significant (p < 0.05) mean sensory scores determined through comparison of wines from five Niagara Peninsula, Ontario Cabernet franc vineyards by descriptive analysis of medium crop size categories, 2010 and 2011 (n= 10 judges; two replicates).

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<th>George (Lincoln Lakeshore North)</th>
<th>Kocsis (Lincoln Lakeshore South)</th>
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<td>2.64a</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red fruit</td>
<td>5.8b</td>
<td>4.6c</td>
<td>7.0a</td>
<td>5.1bc</td>
<td>6.7a</td>
<td>****</td>
</tr>
<tr>
<td>Dark fruit</td>
<td>5.6b</td>
<td>4.8b</td>
<td>5.0b</td>
<td>5.3b</td>
<td>7.0a</td>
<td>****</td>
</tr>
<tr>
<td>Dried fruit</td>
<td>4.1b</td>
<td>5.8a</td>
<td>4.1b</td>
<td>5.6a</td>
<td>5.4a</td>
<td>****</td>
</tr>
<tr>
<td>Bell pepper</td>
<td>3.5a</td>
<td>2.9ab</td>
<td>3.7a</td>
<td>2.9ab</td>
<td>2.6b</td>
<td>*</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>3.6a</td>
<td>4.0a</td>
<td>3.4ab</td>
<td>3.4ab</td>
<td>2.8b</td>
<td>**</td>
</tr>
<tr>
<td>Spice</td>
<td>6.0a</td>
<td>4.7b</td>
<td>5.5ab</td>
<td>4.8b</td>
<td>6.0a</td>
<td>*</td>
</tr>
<tr>
<td><strong>Taste/Mouthfeel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astringency</td>
<td>5.1b</td>
<td>4.2b</td>
<td>5.1b</td>
<td>4.6b</td>
<td>6.6a</td>
<td>****</td>
</tr>
<tr>
<td>Acidity</td>
<td>6.6abc</td>
<td>6.2bc</td>
<td>7.3a</td>
<td>5.9c</td>
<td>6.9ab</td>
<td>**</td>
</tr>
<tr>
<td>Body</td>
<td>5.4b</td>
<td>4.9b</td>
<td>5.0b</td>
<td>4.8b</td>
<td>6.5a</td>
<td>***</td>
</tr>
<tr>
<td>Length</td>
<td>6.5b</td>
<td>5.4c</td>
<td>6.4b</td>
<td>5.1c</td>
<td>7.4a</td>
<td>****</td>
</tr>
</tbody>
</table>

Note: *, **, ***, ****: Significant at p ≤ 0.05, 0.01, 0.001, < 0.0001 respectively. Means followed by different letters are significant at p ≤ 0.05, Duncan’s multiple range test.
Table 7. Impact of site and crop level on three methoxypyrazines, Cabernet franc wines, Niagara Peninsula, Ontario, 2010.

<table>
<thead>
<tr>
<th>Crop level</th>
<th>IPMP (ng L$^{-1}$)</th>
<th>SBMP (ng L$^{-1}$)</th>
<th>IBMP (ng L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>25.46</td>
<td>8.02</td>
<td>59.60</td>
</tr>
<tr>
<td>Low</td>
<td>23.84</td>
<td>9.19</td>
<td>51.59</td>
</tr>
<tr>
<td>Significance</td>
<td>0.423</td>
<td>0.021 *</td>
<td>0.022 *</td>
</tr>
</tbody>
</table>

**Site**

<table>
<thead>
<tr>
<th>Site</th>
<th>IPMP (ng L$^{-1}$)</th>
<th>SBMP (ng L$^{-1}$)</th>
<th>IBMP (ng L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buis</td>
<td>19.58b</td>
<td>8.69b</td>
<td>54.94bc</td>
</tr>
<tr>
<td>Lowrey</td>
<td>22.26b</td>
<td>8.38b</td>
<td>73.34a</td>
</tr>
<tr>
<td>George</td>
<td>26.09b</td>
<td>7.59b</td>
<td>47.81bc</td>
</tr>
<tr>
<td>Kocsis</td>
<td>34.25a</td>
<td>7.94b</td>
<td>45.11c</td>
</tr>
<tr>
<td>Cave Spring</td>
<td>21.06b</td>
<td>10.43a</td>
<td>56.76b</td>
</tr>
<tr>
<td>Significance</td>
<td>0.001 ***</td>
<td>0.010 **</td>
<td>0.0002 ***</td>
</tr>
<tr>
<td>Interaction</td>
<td>0.626</td>
<td>0.047 *</td>
<td>0.004 **</td>
</tr>
</tbody>
</table>

**Buis**

<table>
<thead>
<tr>
<th>Crop level</th>
<th>IPMP (ng L$^{-1}$)</th>
<th>SBMP (ng L$^{-1}$)</th>
<th>IBMP (ng L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>22.23</td>
<td>7.20</td>
<td>50.08</td>
</tr>
<tr>
<td>Low</td>
<td>16.93</td>
<td>10.18</td>
<td>59.80</td>
</tr>
<tr>
<td>Significance</td>
<td>0.486</td>
<td>0.108</td>
<td>0.069</td>
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</table>

**Lowrey**

<table>
<thead>
<tr>
<th>Crop level</th>
<th>IPMP (ng L$^{-1}$)</th>
<th>SBMP (ng L$^{-1}$)</th>
<th>IBMP (ng L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>20.05</td>
<td>8.40</td>
<td>70.35</td>
</tr>
<tr>
<td>Low</td>
<td>24.48</td>
<td>8.35</td>
<td>76.33</td>
</tr>
<tr>
<td>Significance</td>
<td>0.438</td>
<td>0.975</td>
<td>0.352</td>
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**George**

<table>
<thead>
<tr>
<th>Crop level</th>
<th>IPMP (ng L$^{-1}$)</th>
<th>SBMP (ng L$^{-1}$)</th>
<th>IBMP (ng L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>27.20</td>
<td>8.15</td>
<td>50.90</td>
</tr>
<tr>
<td>Low</td>
<td>24.98</td>
<td>7.03</td>
<td>44.73</td>
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<tr>
<td>Significance</td>
<td>0.260</td>
<td>0.183</td>
<td>0.048 *</td>
</tr>
</tbody>
</table>

**Kocsis**

<table>
<thead>
<tr>
<th>Crop level</th>
<th>IPMP (ng L$^{-1}$)</th>
<th>SBMP (ng L$^{-1}$)</th>
<th>IBMP (ng L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>35.50</td>
<td>7.33</td>
<td>60.73</td>
</tr>
<tr>
<td>Low</td>
<td>33.00</td>
<td>8.55</td>
<td>29.50</td>
</tr>
<tr>
<td>Significance</td>
<td>0.766</td>
<td>0.236</td>
<td>0.017 **</td>
</tr>
</tbody>
</table>

**Cave Spring**

<table>
<thead>
<tr>
<th>Crop level</th>
<th>IPMP (ng L$^{-1}$)</th>
<th>SBMP (ng L$^{-1}$)</th>
<th>IBMP (ng L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>22.33</td>
<td>9.00</td>
<td>65.95</td>
</tr>
<tr>
<td>Low</td>
<td>19.80</td>
<td>11.85</td>
<td>47.58</td>
</tr>
<tr>
<td>Significance</td>
<td>0.265</td>
<td>0.189</td>
<td>0.050 *</td>
</tr>
</tbody>
</table>

**Note:** *, **, ***: Significant at p ≤ 0.05, 0.01, or 0.001 respectively. Means followed by different letters are significant at p ≤ 0.05, Duncan’s multiple range test.

**a** Abbreviations: IPMP: Isopropyl methoxypyrazine; SBMP: sec-Butyl methoxypyrazine; IBMP: isobutyl methoxypyrazine.
List of Figures

**Figure 1.** Multi-dimensional scaling of sorted wines from six Riesling sites in the Niagara Peninsula, Ontario, 2010. Abbreviations: H, L = high yield; low yield. Vineyards and their respective Kruskal stress values: A: Buis (0.16), B: Lambert (0.12), C: Lowrey (0.19), D: George (0.19), E: Hughes (0.13), F: Cave Spring (0.12). Ellipses are present for ease of interpretation only, and do not represent confidence intervals or statistical groupings.

**Figure 2.** Multi-dimensional scaling of sorted wines from five Riesling sites in the Niagara Peninsula, Ontario, 2011. Abbreviations: H, L = high yield; low yield. Vineyards and their respective Kruskal stress values: A: Buis (0.19), B: Lowrey (0.19), C: George (0.19), D: Hughes (0.19), E: Cave Spring (0.21). Ellipses are present for ease of interpretation only, and do not represent confidence intervals or statistical groupings.

**Figure 3.** Multi-dimensional scaling of sorted wines from five Cabernet franc sites in the Niagara Peninsula, Ontario, 2010. Abbreviations: H, L = high yield; low yield. Vineyards and their respective Kruskal stress values: A: Buis (0.16), B: Lowrey (0.15), C: George (0.18), D: Kocsis (0.09), F: Cave Spring (0.15). Ellipses are present for ease of interpretation only, and do not represent confidence intervals or statistical groupings.

**Figure 4.** Multi-dimensional scaling of sorted wines from five Cabernet franc sites in the Niagara Peninsula, Ontario, 2011. Abbreviations: H, L = high yield, low yield. Vineyards and their respective Kruskal stress values: A: Buis (0.08), B: Lowrey (0.18), C: George (0.12), D: Kocsis (0.09), F: Cave Spring (0.15). Ellipses are present for ease of interpretation only, and do not represent confidence intervals or statistical groupings.

**Figure 5.** Mean intensity for Riesling wine aroma (lowercase) and flavour /taste (uppercase) attributes for high and low naturally varying yield categories produced from six vineyards, Niagara Peninsula, Ontario, 2010. Values shown are the mean ratings of 12 judges, triplicate fermentation replicates and duplicate assessments. Sites are: A: Buis; B: Lambert; C: Lowrey; D: George; E: Hughes; F: Cave Spring. *,**,***: Significant $P < 0.05, 0.01, 0.001$, respectively.

**Figure 6.** Mean intensity for Riesling wine aroma (lowercase) and flavour /taste (uppercase) attributes for high and low naturally varying yield categories produced from four vineyards, Niagara Peninsula, Ontario, 2011. Values shown are the mean ratings of 12 judges, triplicate fermentation replicates and duplicate assessments. Sites are: A: Buis; B: Lowrey; C: Hughes; D: Cave Spring. *,**,***: Significant $P < 0.05, 0.01, 0.001$, respectively.

**Figure 7.** Mean intensity for Cabernet franc wine aroma (lowercase) and flavour /taste/mouthfeel (uppercase) attributes for high and low naturally varying yield categories produced from five vineyards, Niagara Peninsula, Ontario (2010). Values shown are the mean ratings of 12 judges, triplicate fermentation replicates and duplicate assessments. Sites are: A: Buis; B: Lowrey; C: George; D: Kocsis; E: Cave Spring. *,**,***: Significant $P < 0.05, 0.01, 0.001$, respectively.

**Figure 8.** Mean intensity for Cabernet franc wine aroma (lowercase) and flavour /taste/mouthfeel (uppercase) attributes for high and low naturally varying yield categories produced from five vineyards, Niagara Peninsula, Ontario, 2011. Values shown are the mean ratings of 12 judges, triplicate fermentation replicates and duplicate
assessments. Sites are: A: Buis; B: Lowrey; C: George; D: Kocsis; E: Cave Spring. *,**,***: Significant $P < 0.05$, $0.01$, $0.001$, respectively.

**Figure 9.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Riesling wines from different sub-appellations within the Niagara Peninsula, Ontario (PC1 vs. PC2), 2010 vintage. Aroma descriptors are lowercase and flavour/taste descriptors are uppercase. The sub-appellations in the three main sub-regions of the Niagara Peninsula are depicted in white (Lakeshore), grey (Lake Plain, Lakeshore south), and black (Escarpment Bench).

**Figure 10.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Riesling wines from different sub-appellations within the Niagara Peninsula, Ontario (PC1 vs. PC2), 2011 vintage. Aroma descriptors are lowercase and flavour/taste descriptors are uppercase. The sub-appellations in the three main sub-regions of the Niagara Peninsula are depicted in white (Lakeshore), grey (Lake Plain, Lakeshore south), and black (Escarpment Bench).

**Figure 11.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Riesling wines from six vineyards produced from different naturally varying crop levels from the Niagara Peninsula, Ontario (PC1 vs. PC2), 2010 vintage. Aroma descriptors are lowercase and flavour/taste descriptors are uppercase. The yield categories are depicted in grey (low yield) and black (high yield).

**Figure 12.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Riesling wines from five vineyards produced from different naturally varying crop levels from the Niagara Peninsula, Ontario (PC1 vs. PC2), 2011 vintage. Aroma descriptors are lowercase and flavour/taste descriptors are uppercase. The yield categories are depicted in grey (low yield) and black (high yield).

**Figure 13.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Cabernet franc wines from different sub-appellations within the Niagara Peninsula, Ontario (PC1 vs. PC2), 2010 vintage. Aroma descriptors are lowercase and flavour/taste/mouthfeel descriptors are uppercase. The sub-appellations in the three main sub-regions of the Niagara Peninsula are depicted in white (Lakeshore), grey (Lake Plain, Lakeshore south), and black (Escarpment Bench).

**Figure 14.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Cabernet franc wines from different sub-appellations within the Niagara Peninsula, Ontario (PC1 vs. PC2), 2011 vintage. Aroma descriptors are lowercase and flavour/taste/mouthfeel descriptors are uppercase. The sub-appellations in the three main sub-regions of the Niagara Peninsula are depicted in white (Lakeshore), grey (Lake Plain, Lakeshore south), and black (Escarpment Bench).

**Figure 15.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Cabernet franc wines from five vineyards produced from different naturally varying crop levels from the Niagara Peninsula, Ontario (PC1 vs. PC2), 2010 vintage. Aroma descriptors are lowercase and flavour/taste/mouthfeel descriptors are uppercase. The yield categories are depicted in grey (low yield) and black (high yield).

**Figure 16.** Principal component analysis of sensory, compositional and vine characteristic data of displaying variances of Cabernet franc wines from five vineyards produced from different naturally varying crop levels
from the Niagara Peninsula, Ontario (PC I vs. PC2), 2011 vintage. Aroma descriptors are lowercase and flavour/taste/mouthfeel descriptors are uppercase. The yield categories are depicted in grey (low yield) and black (high yield).
Figure 1.
Figure 3.
Figure 4.

A-BUIS

B-LOWREY

C-GEORGE

D-KOCSIS

E-CAVE SPRING
Figure 5.
Figure 6.
Figure 7.
Figure 8.

A-BUIS

B-LOWREY

C-GEORGE

D-KOCSIS

E-CAVE SPRING
Figure 9.
Figure 10.

Observations (axes PC1 and PC2: 69.69 %)

Variables (axes PC1 and PC2: 69.69 %)

- Active variables
- Supplementary variables

Lincoln Lakeshore South (Hughes)
Beamsville Bench (Cave Spring)
Lincoln Lakeshore North (George)
St. Davids Bench (Lowrey)
Niagara Lakeshore (Buis)
Figure 11.
Figure 12.
For Review Only

Figure 13.

Variables (axes PC1 and PC2: 91.06 %)

Observations (axes F1 and F2: 80.72 %)

- Active variables
- Supplementary variables

https://mc.manuscriptcentral.com/cjps-pubs
Figure 14.

Variables (axes PC1 and PC2: 82.06 %)

- Active variables
- Supplementary variables

Observations (axes PC1 and PC2: 82.06 %)

- Lincoln Lakeshore North (George)
- Four Mile Creek (Lambert)
- St. Davids Bench (Lowrey)
- Lincoln Lakeshore South (Kocsis)
- Beamsville Bench (Cave Spring)
Figure 15.
Figure 16.

Variables (axes PC1 and PC2: 70.79 %)

- Herbaceous
- Bell pepper
- Earthy
- RED FRUIT
- DARK FRUIT
- BELL PEPPER
- HERBACEOUS
- SPICE
- ASTRINGENCY
- ACIDITY
- BODY
- FINISH
- TA
- pH
- Hue
- Colour
- Anthocyanins
- Berry wt.
- Clusters
- Yield
- Dried fruit
- red fruit
- TA
- Clusters
- PC1 (50.59 %)
- PC2 (20.20 %)

Supplementary variables

- Active variables

Observations (axes PC1 and PC2: 70.79 %)

- Buis H
- Kocsis L
- Lowrey H
- Cave Spring H
- George H
- Buis L
- Lowrey L
- Cave Spring L
- George L

PC1 (50.59 %)

PC2 (20.20 %)