

Sensory and chemical characteristics of Canadian ice wines

Canan Nurgel,¹ Gary J Pickering^{1–3*} and Debra L Inglis^{1,2}

¹Cool Climate Oenology and Viticulture Institute, Brock University, 500 Glendridge Ave, St Catharines, Ontario, Canada L2S 3A1

²Department of Biological Sciences, Brock University, Ontario, Canada

³Department of Psychology, Brock University, Ontario, Canada

Abstract: Fifty-one Canadian ice wines, representative of a range of varieties and vintages, were evaluated chemically and 20 wines further evaluated sensorially. Ice wines from British Columbia and Ontario were significantly different for a range of chemical and sensory attributes. British Columbia ice wines had higher titratable acidity, acetic acid and glucose, and lower colour and ethyl acetate content compared with those from Ontario. Apricot, raisin, honey and oak aromas were more pronounced in Ontario ice wines, while British Columbia ice wines had higher intensities of pineapple and oxidized aromas. Riesling ice wines had higher titratable acidity and glucose and lower pH and A_{420} values compared with Vidal. Vintage effects were also found for pH, A_{420} , glucose, fructose, ethanol and ethyl acetate.

© 2004 Society of Chemical Industry

Keywords: Canadian ice wine; chemical and sensory analysis; Vidal; Riesling; Ontario; British Columbia

INTRODUCTION

Ice wine is the late harvest wine made from the juice of grapes that have been frozen on the vine and pressed while frozen. The grapes are harvested at $\leq -8^\circ\text{C}$ and pressed at low temperature to obtain the minimum juice brix of 35° required for ice wine. During pressing, much of the water is retained with the grape skins as ice, while a juice highly concentrated in sugars, acids and aroma compounds is extracted. The juice is then inoculated with yeast and fermentation is carried out at 15–17°C. The high sugar and increasing ethanol concentration place significant stress on the yeast and alcoholic fermentation typically ends while there is still considerable residual sugar present, imparting the sweetness this wine style is renowned for.

Canada possesses climatic and growing conditions conducive to dependable ice wine production, and is now the world's leading producer in terms of quantity and, arguably, quality.¹ The conditions require sufficient sun and heat during summer and autumn to mature the grapes and accumulate sugar, and reliably cold temperatures during late autumn and winter to freeze the fruit and concentrate its content. In Canada the majority of ice wine is produced in two provinces, Ontario (ONT) (~75%) and British Columbia (BC) (~25%).² In Ontario, the principal wine regions are the Niagara Peninsula, and Pelee Island and Lake Erie North Shore in southern Ontario while, in British Columbia, they are the Okanagan

and Similkameen Valleys. A long growing season and high heat units are the two most important characteristics distinguishing these areas from the other wine regions of Canada.³ The character of the wines from these zones is partly due to their climate; they display a balance between sugar, acid and alcohol content, combined with delicate fruity flavours.⁴ Other countries with notable ice wine industries are Germany, Austria, Luxembourg, Croatia, Slovenia, the Czech Republic, Hungary, Romania, Switzerland and the USA.⁵

A wide range of grape varieties are used around the world for ice wine, ranging from Chardonnay to Zweigelt. However, Riesling and Vidal are the most commonly used cultivars; their tough skins confer some protection from disease and the mechanical stress of the freeze/thaw cycle, and they impart desirable fruity aromas and flavours to the finished wines.⁵ Vidal is a French–American hybrid grape variety common in Lake Erie and other areas of eastern North America where cultivation of *Vitis vinifera* grapes is difficult.⁶ The Vidal berries have superior resistance to rot, and table wines made from the variety have been described as 'hybrid, coarse', possessing a fruity varietal character.⁷ Riesling is considered by many industry commentators as the premium variety for ice wine.⁸ It possesses high levels of natural acidity—important for balancing the sweetness of the finished wines—and is better suited to the cool climate

* Correspondence to: Gary J Pickering, Cool Climate Oenology and Viticulture Institute, Brock University, 500 Glendridge Ave, St Catharines, Ontario, Canada L2S 3A1

E-mail: gpickeri@brocku.ca

Contract/grant sponsor: National Science and Engineering Research Council of Canada

(Received 17 December 2003; revised version received 8 April 2004; accepted 8 April 2004)

Published online 4 August 2004

and particularly severe winters of North America than most other *vinifera* varieties.⁹ Table wines produced from Riesling often possess fruity–floral aromas, which may include spicy, apricot and Muscat nuances.¹⁰

While sales and exports of Canadian ice wines have increased dramatically over recent years, there is little in the scientific literature that describes the wines either chemically or sensorially. The only known study² investigated the composition and sensory properties of 22 Canadian and three German ice wines. The authors identified a number of volatile compounds using gas chromatography–mass spectrometry and described their aromas using gas chromatography–olfactometry. Descriptive analysis was also used to profile the wines' sensory characteristics. Some chemical and sensory differences were found between ice wines from Canada and Germany, and between Ontario and British Columbia samples.

The objectives of this current study are to determine the basic chemical quality indicators of a wider and more representative range of Canadian ice wines, as well as to develop sensory profiles of a sub-set of these wines using flavour profiling techniques. These chemical and sensory parameters will be determined with particular consideration to varietal and vintage variation in addition to an examination of regional influences.

EXPERIMENTAL

Materials

Fifty two Canadian ice wines—41 from Ontario and 11 from British Columbia—were obtained from 26 wineries. Varietal representation was: Vidal (27), Riesling (14), Gewürztraminer (3), Chardonnay (2), Pinot Blanc (2), Erhenfelser (1) Erhenfelser–Vidal–Riesling (1) and Kerner (1). Two wines were from the 1995 vintage, five from 1996, 10 from 1997, 17 from 1998, 11 from 1999, and seven wines from 2000. To protect proprietary interests, winery identities have not been reported here. Wines were stored in a wine cellar at 14 °C until required and, after sampling, were re-corked after sparging of the headspace with nitrogen.

Physical and chemical analyses

The pH and titratable acidity (TA) were determined using an ATI Orion model 550 pH meter (Beverly, MA, USA). TA of the wines was determined by titrating 10 ml ice wine with 0.1 M NaOH to a pH of 8.2.¹¹ Color was measured at 420 and 520 nm in 10 mm quartz cells using a spectrophotometer (Genesys 2, CA, USA). Physical viscosity was determined using a 50 ml Cannon Fenske Capillary Viscometer (Cannon Instrument Co, State College, PA, USA) immersed in a 20 °C water bath. All viscometer flux times were determined in triplicate (stop-watch, Heuer). Specific gravity (SG) was measured using a calibrated 25 ml pycnometer equipped with thermometer (KIMAX Chemistry, NY, USA) and immersed in a 20 °C water bath. Glycerol,

glucose and fructose concentrations were determined using enzymatic test kits from Boehringer (Mannheim, Germany).

Ethanol, acetic acid, ethyl acetate and iso-amyl alcohol were measured using gas chromatography (GC; Agilent, CA, USA) equipped with flame ionization detector and Carbowax (30 m × 0.23 mm × 0.25 µm) column. A sample of 0.5 µl wine was injected into the injection port heated to 250 °C. The carrier gas was helium with a column head pressure of 20 psig. The flow rate of helium gas as carrier was 1.8 ml min⁻¹. The oven temperature was programmed to start at 60 °C, increase to 125 °C at 6 °C min⁻¹, and then increase to 225 °C at 25 °C min⁻¹ and hold for 1 min. The detector temperature was 250 °C and 1-butyl alcohol was used as an internal standard. Standards were purchased from Sigma (Sigma Chemical Co, Oakville, Canada) and measurements of all samples and standards were performed in triplicate.

Sensory evaluation

A sub-set of 20 ice wines from the chemical study was selected for sensory evaluation based on their representation of a range of varieties and vintages from within Ontario (11) and British Columbia (9). The basic composition of these wines is shown in Table 1.

Panel training

Descriptive sensory evaluation was carried out by a panel of nine trained judges, all of whom were students or staff of Brock University, Canada. They were selected on the basis of their interest and availability, and ages ranged between 21 and 55 years. All panellists had previous experience in wine tasting and some panellists had experience in descriptive analysis studies. The panel also had experience in assessing density and viscosity in model ice wines from an earlier study.¹²

The panel was trained in four sessions over 2 weeks to describe the aroma properties of the ice wines. Eight of the ice wines were presented during training and considered representative of the varieties, vintages and provinces that were to be formally evaluated. The panel was presented with the descriptive terms used by Cliff *et al*² and Noble *et al*¹³ as a guide to establishing an appropriate lexicon. By panel consensus, three appearance, 11 aroma and five terms describing oral sensations were derived to define the wines. Reference standards were prepared and modified after panel feedback to represent these descriptors (Table 2), and were used with the wines during training to 'calibrate' the panel. Line scales were introduced, appropriate anchor terms derived by consensus for each term, and exercises completed to aid in the use of the standards and scales to reliably assess descriptor intensity.

A final session was held prior to formal data collection to familiarize the panel with the computer program (Compusense FiveTM, C5V4, Guelph, Ontario,

Table 1. Basic composition of ice wines used in sensory study^a

Vintage	Variety	Province ^b	pH	Titrateable acidity (g l ⁻¹)	Residual sugar (g l ⁻¹)	Ethanol (% v/v)	A ₄₂₀
2000	Chardonnay	BC	3.7	13.0	225.2	10.8	0.372
2000	Chardonnay	BC	3.9	13.2	220.7	9.0	0.257
2000	Erhenfelser	BC	3.5	12.8	301.5	9.6	0.275
1998	E-V-R ^c	BC	3.6	9.8	196.3	10.9	0.307
1999	Kerner	BC	3.6	11.8	148.0	12.6	0.241
1998	Pinot Blanc	BC	3.6	9.5	213.2	9.4	0.430
1998	Pinot Blanc	BC	3.5	10.2	248.0	9.5	0.322
1997	Riesling	BC	3.1	16.8	181.0	9.6	0.419
1998	Vidal	BC	3.4	13.1	275.3	8.4	0.471
1998	Riesling	ONT	3.2	11.1	226.5	9.1	0.278
1998	Riesling	ONT	3.2	8.8	260.7	9.5	0.244
1999	Riesling	ONT	3.2	10.2	149.5	12.2	0.225
2000	Riesling	ONT	3.4	10.8	223.3	10.1	0.181
1997	Vidal	ONT	3.1	8.5	184.5	9.8	0.608
1999	Vidal	ONT	3.7	7.5	203.1	11.5	0.394
1999	Vidal	ONT	3.7	9.0	242.8	11.9	0.431
2000	Vidal	ONT	3.6	12.6	236.6	9.3	0.259
1997	Oak-aged Vidal	ONT	3.1	9.0	183.6	9.5	0.760
1998	Oak-aged Vidal	ONT	3.3	10.9	269.1	9.1	0.498
1999	Oak-aged Vidal	ONT	3.5	8.4	216.3	12.0	0.403

^a Data represent the mean value of duplicate measurements per sample; ^b BC, British Columbia; ONT, Ontario; ^c E-V-R, Erhenfelser–Vidal–Riesling.

Canada) that was used to collect the sensory data. This session was conducted under the same experimental conditions as used for actual testing. The data obtained was used for assessing panellists' reliability, which was considered acceptable ($p < 0.05$ for reproducibility of scores of replicate samples). All ice wines for both training and formal testing were served as 18 ml samples in ISO glasses at 19 ± 1 °C.

Test procedure

Twenty samples (Table 1) were analysed in duplicate by trained panellists over five sessions using a balanced, complete block design. Each test session consisted of two flights and each flight contained four wine samples coded with random three-digit numbers, with the order of samples randomized in each flight. Descriptor intensities were scored on individual 15 cm scales (Table 2). The evaluations were conducted in the specialized sensory evaluation laboratory at Brock University, with each panellist assigned to an individual booth equipped with red lighting to mask any potential colour differences between samples during the assessment of aroma and oral sensations. White light and white background were used during the assessment of ice wine colour.

The panel assessed colour and aroma (ortho-nasal) during 1 h morning sessions and oral sensations during 1 h afternoon sessions. Prior to each session, instructions were given on the protocol for assessing the samples. Panellists were required to re-familiarize themselves with reference standards for the three colour, 11 aroma and five oral sensation attributes, and were able to refer back to them as needed during their evaluation. Minimum breaks of 2 min between each sample and 10 min between flights were imposed

to minimize fatigue and carry-over effects. During the evaluation of oral sensations, the protocol required expectoration of samples, rinsing of mouth between samples with Brita™ filtered water (Brita, Wiesbaden, Germany) and the use of nose clips to eliminate the potentially confounding effect of aroma.

Data analysis

All statistical analyses were performed using the SPSS version 10.0 for Windows statistical package (SPSS Inc, Chicago, IL, USA). To evaluate panel performance, the general linear model was used to examine panellist, replicate and stimuli effects and their interactions. Analysis of variance (ANOVA) was used to determine the effects of panellist (P), wines (W), replicates (R) and $W \times P$, $P \times R$ and $W \times R$ interactions for all appearance, aroma and oral sensation attributes.

Mean scores of significant sensory attributes ($p < 0.05$) were plotted on cobweb diagram. Principal component analysis (PCA) was performed on chemical composition data and on the mean sensory scores using the correlation matrices. An independent sample t -test was used to compare the means of the chemical data for Ontario and British Columbia, and ANOVA was used to determine the effect of vintage year on composition of the ice wines.

RESULTS AND DISCUSSIONS

Table 3 shows the mean physical and chemical values for the wines for province, variety and year.

Physicochemical: main effects

The elevated levels of residual sugar and, to a lesser extent, acidity, compared with table wines were

Table 2. Composition of reference standards used to describe the appearance aroma and oral sensations elicited by ice wines

Descriptor	Composition ^a
<i>Appearance</i>	
Pale yellow	Riesling ice wine, 2000, Henry of Pelham, Ontario
Golden yellow	Riesling ice wine, 1997, Cedar Creek, British Columbia
Golden copper	Oak-aged Vidal ice wine, 1997, Hillebrand, Ontario
<i>Aroma</i>	
Pineapple	4 ml canned pineapple juice (Delmontt Quality™)
Apple	20 ml apple sauce (No name™)
Apricot	8 ml dry apricot puree soaked in water overnight
Raisin	30 dry raisins puree soaked in water 1 h
Honey	4 g honey (Clover, Bill Bee™)
Caramel	2.5 g caramel (Starbuck Caramel™)
Walnut	Ground walnut (without base ice wine)
Citrus	Freshly squeezed lemon juice (5 ml) + grapefruit juice (5 ml)
Floral	1 drop linalool (Sigma Aldrich)
Oxidized	1 drop acetaldehyde (Fisher, Scientific)
Oak	0.5 g oak chips soaked for 1 h
Sweetness	300 g l ⁻¹ sugar (glucose:fructose1/3) (Sigma Aldrich)
<i>Oral sensations</i>	
<i>Viscosity</i>	
Very thin	Distilled water
Very thick	2 g l ⁻¹ carboxyl methyl cellulose (Sigma Aldrich)
Reference viscosity	0.3 g l ⁻¹ carboxyl methyl cellulose
<i>Density</i>	
Very light	Distilled water
Very heavy	2 g l ⁻¹ carboxyl methyl cellulose
Reference density	0.3 g l ⁻¹ carboxyl methyl cellulose
Heat	14% ethanol
Bitterness	0.1 g l ⁻¹ quinine sulphate

^a Unless otherwise indicated, aroma standards were prepared in 40 ml base ice wine and oral standards made up in distilled water. References were prepared 2 h before evaluation and presented in ISO glasses.

apparent, with average values of 215 g l⁻¹ for total residual sugar (glucose + fructose) and 11 g l⁻¹ for titratable acidity. Sugar and acid have suppressive effects on each other with respect to perceived sweetness and acidity,¹⁴⁻¹⁶ and it is the balance between these two components that contributes significantly to the consumer appeal of ice wine. A residual sugar:acid ratio of approximately 20:1 has been suggested as providing optimum balance between the taste sensations in ice wine.⁵

The elevated residual sugar levels would be expected to pose significant challenges with respect to the microbial stability of these wines, and necessitate protection with anti-microbial additives such as sorbate and sulphur dioxide. The 2:1 ratio of fructose to glucose in the final wines is similar to that found in table wine.¹⁷

Table 3. Means and corresponding standard deviations for the physicochemical composition of 51 Canadian ice wines^a

	Titratable Acidity (g l ⁻¹)	pH	420 nm	520 nm	Specific gravity	Viscosity (cp)	Glucose (g l ⁻¹)	Fructose (g l ⁻¹)	Ethanol (% v/v)	Acetic acid (g l ⁻¹)	Glycerol (g l ⁻¹)	Ethyl acetate (g l ⁻¹)	Iso-amyl alcohol (g l ⁻¹)
Overall means (n = 51)	10.7 ± 1.9	3.4 ± 0.2	0.484 ± 0.21	0.117 ± 0.11	1.089 ± 0.018	3.2 ± 0.3	71.4 ± 17.9	143.3 ± 20.0	10.2 ± 1.2	1.3 ± 0.5	12.4 ± 3.1	0.24 ± 0.07	0.067 ± 0.020
British Columbia (n = 11)	12.2 ± 2.1	3.5 ± 0.2	0.354 ± 0.08	0.064 ± 0.02	1.093 ± 0.016	3.4 ± 0.4	81.6 ± 20.1	142.3 ± 24.9	10.0 ± 1.1	1.6 ± 0.4	13.4 ± 3.0	0.20 ± 0.08	0.069 ± 0.008
Ontario (n = 40)	10.2 ± 1.7	3.4 ± 0.2	0.519 ± 0.22	0.132 ± 0.12	1.088 ± 0.018	3.2 ± 0.3	68.6 ± 16.7	143.6 ± 20.0	10.2 ± 1.1	1.2 ± 0.5	12.1 ± 3.1	0.25 ± 0.09	0.066 ± 0.022
Riesling (n = 14)	11.8 ± 2.3	3.2 ± 0.1	0.365 ± 0.12	0.121 ± 0.19	1.096 ± 0.026	3.2 ± 0.3	78.7 ± 17.2	140.5 ± 10.0	10.0 ± 1.1	1.2 ± 0.4	12.6 ± 3.6	0.27 ± 0.06	0.063 ± 0.020
Vidal (n = 28)	9.9 ± 1.6	3.5 ± 0.2	0.596 ± 0.22	0.134 ± 0.05	1.086 ± 0.012	3.1 ± 0.4	66.8 ± 15.0	149.2 ± 15.3	10.3 ± 1.1	1.3 ± 0.5	11.4 ± 1.3	0.25 ± 0.06	0.067 ± 0.020
Gewurztraminer (n = 3)	9.7 ± 1.0	3.3 ± 0.2	0.421 ± 0.07	0.090 ± 0.02	1.085 ± 0.007	3.0 ± 0.1	57.2 ± 16.1	109.9 ± 23.5	9.5 ± 1.6	1.0 ± 0.7	16.8 ± 7.2	0.27 ± 0.06	0.071 ± 0.010
Years													
1995 (2)	10.9 ± 0.6	3.6 ± 0.2	0.943 ± 0.09	0.173 ± 0.03	1.076 ± 0.005	3.1 ± 0.1	53.0 ± 4.3	137.7 ± 1.7	11.1 ± 0.5	1.2 ± 0.2	9.5 ± 0.5	0.18 ± 0.01	0.061 ± 0.001
1996 (4)	11.5 ± 0.9	3.4 ± 0.1	0.789 ± 0.20	0.175 ± 0.05	1.082 ± 0.005	2.9 ± 0.2	60.2 ± 5.4	129.8 ± 16.4	9.3 ± 0.4	0.9 ± 0.3	13.3 ± 3.1	0.27 ± 0.06	0.082 ± 0.021
1997 (10)	10.4 ± 2.5	3.3 ± 0.2	0.522 ± 0.13	0.182 ± 0.20	1.082 ± 0.007	3.0 ± 0.2	60.3 ± 9.7	124.7 ± 19.4	10.3 ± 0.6	1.2 ± 0.5	14.1 ± 4.9	0.27 ± 0.45	0.067 ± 0.006
1998 (17)	10.2 ± 1.6	3.4 ± 0.2	0.440 ± 0.12	0.094 ± 0.04	1.098 ± 0.024	3.3 ± 0.2	80.1 ± 13.9	152.5 ± 13.0	9.7 ± 1.1	1.4 ± 0.5	12.3 ± 2.8	0.26 ± 0.06	0.066 ± 0.031
1999 (11)	10.1 ± 2.5	3.4 ± 0.2	0.329 ± 0.07	0.073 ± 0.04	1.088 ± 0.014	3.2 ± 0.3	67.2 ± 21.1	149.7 ± 22.5	11.1 ± 1.3	1.2 ± 0.0	11.8 ± 2.1	0.25 ± 0.04	0.066 ± 0.017
2000 (7)	12.0 ± 1.3	3.6 ± 0.2	0.403 ± 0.21	0.088 ± 0.07	1.0919 ± 0.016	3.3 ± 0.4	78.9 ± 22.3	149.6 ± 17.5	10.1 ± 0.8	1.6 ± 0.6	11.3 ± 1.3	0.11 ± 0.04	0.063 ± 0.011

^a Data represent the mean value of duplicate measurements per sample.

Glycerol concentration ranged between 7.1 and 25.0 g l⁻¹, with an average of 12.4 g l⁻¹. Reported values for table wine are 1.4–10.6 g l⁻¹,^{18–20} and higher levels in ice wine have been postulated to be a response to the osmotic stress imposed from the high sugar concentration.^{21,22} At the levels found here, glycerol may contribute to the sweetness,¹² but not to the perceived viscosity or density elicited by ice wines.^{12,23}

The physical viscosity of the ice wines averaged 3.2 cp (Table 3), approximately 10% higher than the weighted average of Canadian ice wines found by Cliff *et al.*,² and 30% higher than the small sample of German ice wines reported in the same paper. This reflects a viscosity approximately twice that found in table wines (1.2–1.7 cp).^{24–26} In model ice wines, Nurgel and Pickering¹² showed that residual sugar contributes most to physical viscosity, followed by ethanol, with a minor contribution from glycerol content.

The high viscosity of the ice wines may also impact on the perception of aroma and oral sensations. Increasing viscosity has been shown to decrease the perceived intensities of both volatile and non-volatiles in solutions containing varying concentration of hydroxyl propyl methylcellulose,²⁷ with the effect on volatile compounds due to overlapping hydrocolloids decreasing compound mobility and therefore the dynamics of flavour release.²⁸ Viscosity has also been shown to reduce the perception of astringency^{29,30} and sourness³⁰ of aqueous solutions.

Acetic acid is an important component influencing the final quality of wine. At elevated levels it is associated with spoilage, and limits in wine are legislated in most wine-consuming nations. In Canada, the maximum allowable content in ice wine is 2.1 g l⁻¹. As Table 3 shows, acetic acid levels ranged between 0.49 and 2.29 g l⁻¹ with an average of 1.30 g l⁻¹, in agreement with Mottiar³¹ and Nurgel *et al.* (unpublished data). In contrast, Cliff *et al.*² reported an average acetic acid content of 33.55 mg l⁻¹ (relative to an internal tetradecane standard) for 22 Canadian ice wines; this value is well below any previously reported concentration in the literature, even for table wine.^{17,18} In table wines, acetic acid concentration is influenced by yeast species and strain, juice sugar concentration, pH, nitrogen content and fermentation temperature.³² In ice wine, yeasts produce higher amounts of acetic acid as part of the process of maintaining redox balance in response to the osmotic stress imposed by the high sugar levels.^{21,22} The sensory threshold for acetic acid in table wine is around 1.3 g l⁻¹ in table wine,³³ but it is believed to be higher in ice wine (Cliff and Pickering, unpublished data).

Ethyl acetate is the main ester in wine, usually accounting for well over 50% of the total ester content.¹⁸ At low levels it can contribute some complexity to a wine's sensory profile while, at higher levels, it is considered a fault. Table 2 shows ethyl

acetate concentrations ranging from 86 to 369 mg l⁻¹, with an average value of 240 mg l⁻¹. Reported values in table wines range between 0.15 and 150 mg l⁻¹.³⁴ The sensory threshold in table wine for ethyl acetate has been determined as being between 12 and 170 g l⁻¹,³³ although it is believed to be higher in ice wine (Cliff and Pickering, unpublished data).

Iso-amyl alcohol is one of the major contributors to the higher alcohol fraction of wines.¹⁸ In the ice wines, concentrations ranged from 43 to 165 mg l⁻¹, with an average of 67 mg l⁻¹. The concentrations and threshold values for isoamyl alcohol reported in table wine are 490 and 14.5 mg l⁻¹, respectively.^{34,35} The overall concentration of higher alcohols has previously been determined as higher in musts of high sugar content.³⁴ The contribution of isoamyl alcohol to ice wine aroma and flavour is unknown.

Spectrophotometric measurements of white wine at 420 and 520 nm can indicate degree of browning and pinking, respectively.¹⁷ *A*-420 and *A*-520 nm values were 0.181–1.015 and 0.024–0.230, respectively. The 420 nm values are in agreement with those reported by Cliff *et al.*² The 520 nm data agree with those previously reported in table wine,^{36,37} but are approximately 200× higher than the very low values reported in Canadian ice wine by Cliff *et al.*² Further consideration of the colour of these wines is given later when the sensory results are discussed.

Physicochemical: origin, variety and vintage variation

Principal component analysis was performed on the chemical composition data on the sub-set of wines that was also used for sensory analysis, and the results are presented in Fig 1. The first two principal components account for 61% of the variation in the data set. Principal component 1 is positively loaded for residual sugar and its physical correlates of viscosity and specific gravity, while negatively loaded for ethanol.

Principal component 2 is positively loaded for the spectrophotometric measurements of wine hue (*A*₅₂₀ and *A*₄₂₀) and acetic acid content, and negatively loaded primarily for pH. A tight grouping of Ontario wines is located in the upper left quadrant of the plot, characterized largely by high colour and ethyl acetate. Cliff *et al.*² found similar provincial separation based on higher colour values in Ontario wines although, in contrast, our data indicate lower pH values in Ontario wines (Table 3). Four out of nine of the wines from British Columbia form a loose cluster diagonally transecting the lower left and right quadrants and largely characterized by high negative vector loadings for pH and iso-amyl alcohol. Two wines from British Columbia are located together on PC1 to the right of the origin with high loadings for fructose, glucose, specific gravity and viscosity. This latter grouping is consistent with Cliff *et al.*,² where wines from British Columbia were generally clustered together based

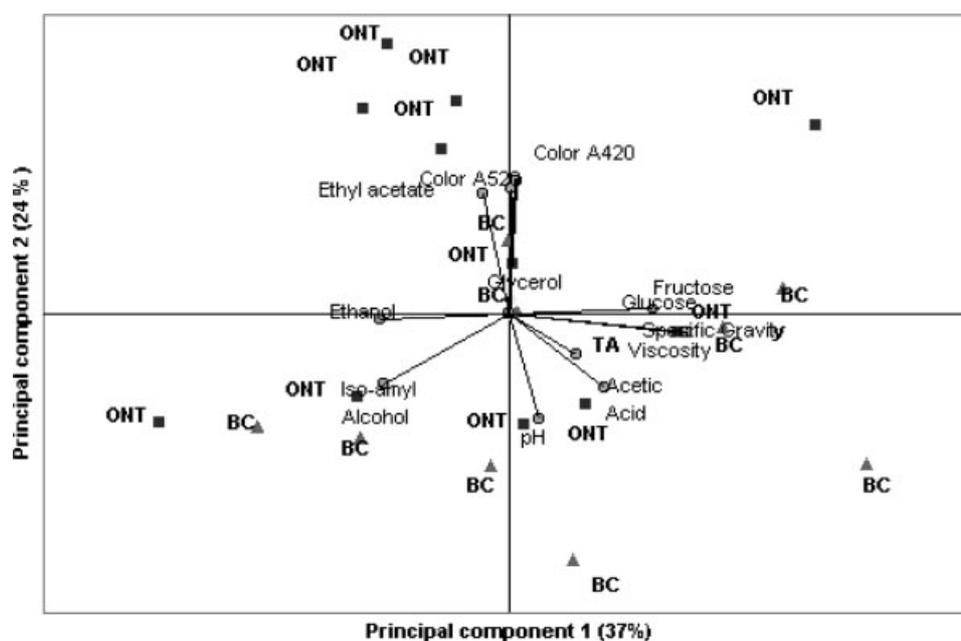


Figure 1. Principal component analysis of physiochemical data for British Columbia (BC, $n = 9$) and Ontario (ON, $n = 11$) ice wines.

on high vector loadings for TA, total sugar and viscosity.

Wines from British Columbia had higher TA ($t = 3.258, p = 0.002$) and glucose contents ($t = 2.416, p = 0.019$) than their Ontario counterparts, consistent with Cliff *et al.*² as well as higher acetic acid content ($t = 2.399, p = 0.020$; Table 3). Ontario ice wines had higher A_{420} values ($t = 2.368, p = 0.022$), consistent with Cliff *et al.*² and higher ethyl acetate content ($t = 2.553, p = 0.014$).

Riesling ice wines had higher TA ($t = 3.195, p = 0.003$) and glucose ($t = 2.535, p = 0.016$) and lower pH ($t = 4.653, p = 0.000$) and A_{420} values ($t = 3.387, p = 0.002$) compared with Vidal. Main and Morris³⁷ also reported lower browning in Riesling table wines after 3 months of ageing compared with Vidal, and suggested it may be due to Vidal's generally higher pH and greater phenol content. The higher TA of Riesling shown here is consistent with many anecdotal comments from the wine community espousing Riesling ice wine for its superior (higher) acid:sweetness balance.

Vintage is universally regarded as a major source of variation in wine composition and quality across styles and grape growing regions of the world. Vintage had significant effect on pH ($p = 0.023$), colour at A_{420} ($p = 0.000$), glucose ($p = 0.017$), fructose ($p = 0.009$), ethanol ($p = 0.011$) and ethyl acetate ($p = 0.000$). As expected, A_{420} values were higher in older vintages, age-related phenomena consistent with the gradual formation of brown pigments witnessed in table wines.

The 1996 and 1997 vintages had lower fructose contents than other years. This is likely to be related to different conditions or temperature profiles during harvest. Residual sugar amounts also changed with vintages of ice wines.

Sensory evaluation: main effects

Results of ANOVA for attribute scores are summarized in Table 4. Sources of variation were wines (W), panellist (P), tasting replicate (R), wine and panellist interaction ($W \times P$), panellist and replicate interaction ($P \times R$) and wine and replicate interaction ($W \times R$). There was a significant main effect for 14 of the 17 sensory attributes measured (all $p < 0.001$). As expected, panellist was also a significant effect ($p < 0.001$) for all attributes, indicating that not all judges evaluated all samples in the same fashion, possibly due to idiosyncratic use of the intensity scales. This is a common result in sensory evaluation studies.³⁸ Replicate and replicate \times wines effects were generally not significant, indicating consistency in rating between sessions and wines. The interaction between panellist and replicate was significant only for sweetness and color, indicating that panellists rated most of the attributes consistently from session to session.

Sensory evaluation: origin, variety and vintage variation

ANOVA was performed in order to characterize sensory differences between the British Columbia and Ontario ice wines. Seven aroma or colour attributes were found to be significantly different, and their mean scores are shown as a cobweb plot in Fig 2. As shown, Ontario ice wines were more deeply coloured, and characterised by higher intensities of *apricot*, *raisin*, *honey* and *oak* aromas. Wines from British Columbia had higher intensities of *pineapple* and *oxidized* aromas. Where similarities in the selection of descriptive terms allow comparison, these results are similar to the provincial profiles reported by Cliff *et al.*² except for *pineapple* aroma; in their study the attribute *tropical*

Table 4. F-values from analysis of variance of, taste, mouthfeel and colour attributes in Canadian ice wines for aroma (20 wines, nine judges and two replicates)

	Wine (W)	Panellist (P)	Rep (R)	W × P	P × R	W × R
<i>Appearance</i>	44.11***	8112.78***	21.81***	1.56***	5.15***	1.21
<i>Aroma</i>						
Apple	1.47	32.72***	0.08	1.38**	1.08	1.15
Apricot	1.55	62.76***	0.33	1.53***	2.02	1.11
Citrus	2.95***	56.30***	2.62	1.47**	0.91	0.50
Pineapple	2.44***	37.33***	0.67	1.61***	0.48	0.83
Floral	2.59***	18.72***	6.08**	1.14	1.20	0.75
Raisin	2.38***	65.92***	3.44	1.24	1.16	0.87
Honey	3.39***	75.59***	2.89	2.05***	1.69	1.06
Caramel	3.41***	31.58***	2.08	1.48**	1.09	0.76
Walnut	2.18***	46.61***	1.20	1.53***	1.17	0.99
Oxidized	3.77***	5.58***	0.15	2.51***	1.21	0.85
Oak	2.98***	15.65***	1.41	1.60***	1.01	0.70
<i>Oral sensations</i>						
Density	2.34***	26.18***	0.66	1.29	0.73	0.64
Viscosity	2.67***	32.89***	0.73	1.35**	1.46	0.64
Sweetness	4.61***	56.43***	4.25*	1.80***	4.79***	0.86
Heat	1.57	69.01***	1.95	1.05	0.82	0.57
Bitterness	2.50***	127.23***	5.91**	1.63***	1.58	0.50

* Significance level at 5%.
 ** Significance level at 1%.
 *** Significance level at 0.1%.

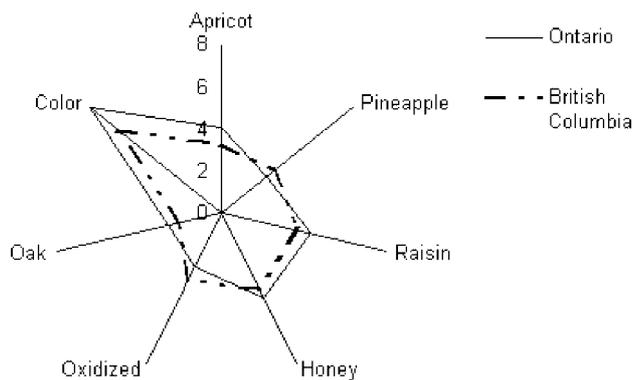


Figure 2. Cobweb plot of the mean intensity ratings for color and aroma attributes of 20 ice wines from British Columbia ($n = 9$) and Ontario ($n = 11$) (nine panellists × two repetitions). (Only attributes that are statistically different (t -test) are displayed).

fruit/pineapple was rated more intensely in ice wines from Ontario.

The mean sensory ratings of all attributes were analysed by PCA and the relationship between sensory attributes and province are shown in Fig 3. Thirty-two percent of variation in the data was explained by PC1 and 16% by PC2. PC 1 is largely characterized by the contrast of fruity and floral attributes (with mostly negative loadings except for apricot aroma) with caramel aroma, raisin aroma and colour (with positive loadings). PC 2 is less well defined, although a contrast of oxidized (positive loadings) with floral and fruity attributes (negative loading) has some interpretive value.

Perceived viscosity, density and sweetness appear positively correlated with each other and negatively

correlated with a loose grouping of BC wines observed in the lower right quadrant, largely reflecting high bitterness and low sweetness, density and viscosity scores. However, overall, there is a disperse scattering of provinces in all four quadrants.

Cliff *et al*² investigated variation in oral sensations by origin using PCA, and concluded that British Columbia ice wines formed a looser cluster than Ontario wines, suggesting a broader range of sensory attributes. Our data do not support this conclusion. The higher glucose, physical viscosity and TA values of the British Columbia wines (Table 2) have not translated into obvious differences in oral sensations compared with Ontario wines, nor in predicting sensory clusters in this sample.

As Riesling and Vidal are the two most widely used grape varieties for ice wine, we used ANOVA to test for any differences in their sensory profiles. Four aroma and colour attributes were significantly different ($p < 0.05$), and their mean intensity scores are shown in Fig 4. Vidal was significantly higher than Riesling for raisin, honey, oak, caramel and colour, possibly related to inclusion of three oak-aged ice wines in the sample set. By comparison, Riesling ice wine is rarely aged in oak in Canada. Using GC olfactometry, Cliff *et al*² identified a number of compounds in ice wine associated with honey (benzenemethanol; 1,3-propanediol diacetate; methyl vanillate; hexanoic acid and 5-(cyclohexylmethyl)-2-pyrrolidinone) and caramel (diethyl hydroxybutanedioate; ethyl isopentylsuccinate; dihydro-2(3H)-furanone; and 5-(cyclohexylmethyl)-2-pyrrolidinone) although their relative odor activity and variance with variety have not been reported.

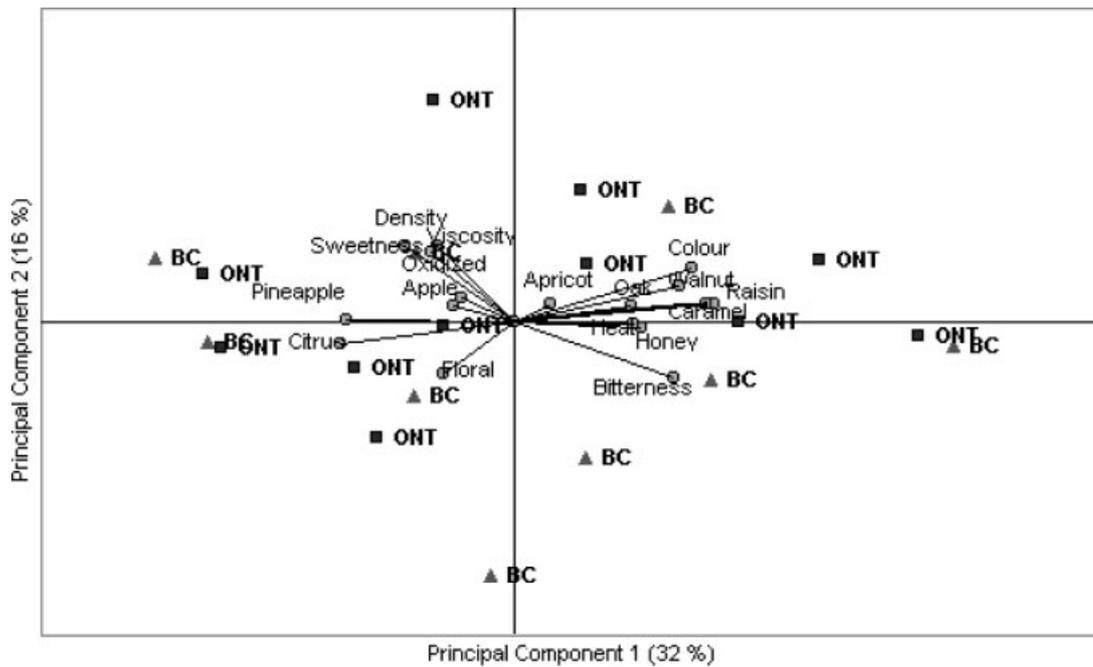


Figure 3. Principal component analysis of mean sensory scores for ice wines from of British Columbia (BC, $n = 9$) and Ontario (ONT, $n = 11$).

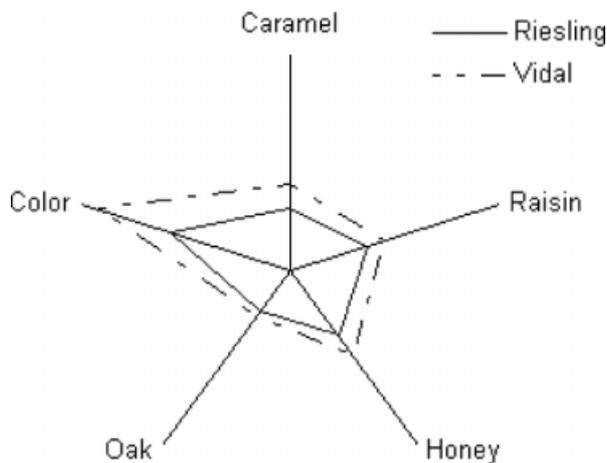


Figure 4. Cobweb plot of the mean intensity ratings for sensory attributes of 13 ice wines produced from Riesling ($n = 5$) and Vidal ($n = 8$) (nine panellist \times two repetitions). (Only attributes that are statistically different (t -test) are displayed).

The relationship between the sensory attributes of all six varietal and one blended wine(s) was examined using PCA, with the principal component plot shown in Fig 5. Interpretation of factor loadings is given below.

Five of the eight Vidal wines form a loose grouping to the right of the plot, partly reflecting their lower intensities for floral and fresh fruit attributes. A tighter sub-group comprising the three oaked Vidal wines is observed on or close to the PC1 axis, reflecting their higher scores for attributes often associated with oak aging—caramel, oak, walnut and colour intensity. By contrast, Riesling wines form a loose group centred to the left of the plot, based largely on higher scores for floral, fresh fruit, and to a lesser extent oxidized attributes. The remaining four varietals

and one blended wine are represented by very low n s (1 or 2); extreme caution should be applied in generalizing from their locations within the PC space. One of the Chardonnay ice wines is located in the lower left quadrant, a space positively loaded with the pineapple, citrus and floral attributes and the other is located in the upper right segment of the plot loaded with caramel, walnut and raisin aromas.

The two Pinot Blancs and one Kerner wine are located toward the bottom right of the plot. The table versions of these two varieties are generally regarded as relatively neutral wines; their location here is consistent with that, as they are negatively correlated with fruity and floral descriptors. The sole Erhenfelser wine is located along the PC1 axis within the general grouping of Riesling wines. By contrast, the one Erhenfelser–Vidal–Riesling blend wine is located within the loose cluster of Vidal wines described above, suggesting that the Vidal component is playing a dominant role in the sensory profile of the wine.

CONCLUSIONS

The set of commercial Canadian ice wines evaluated was differentiated both physicochemically and sensorially. Regional, variety and vintage variation were noted for both chemical and sensory attributes. PCA distinguished provincial wines more clearly by their composition than by their sensory attributes. In contrast, varietal wines were successfully discriminated from each other by their sensory characteristics. In general our results are in agreement with the study of Cliff *et al.*,² although important differences exist, particularly in the much higher acetic acid and A_{520} data reported here.

Further research is required into the specific mechanisms by which macroclimate and wine-making

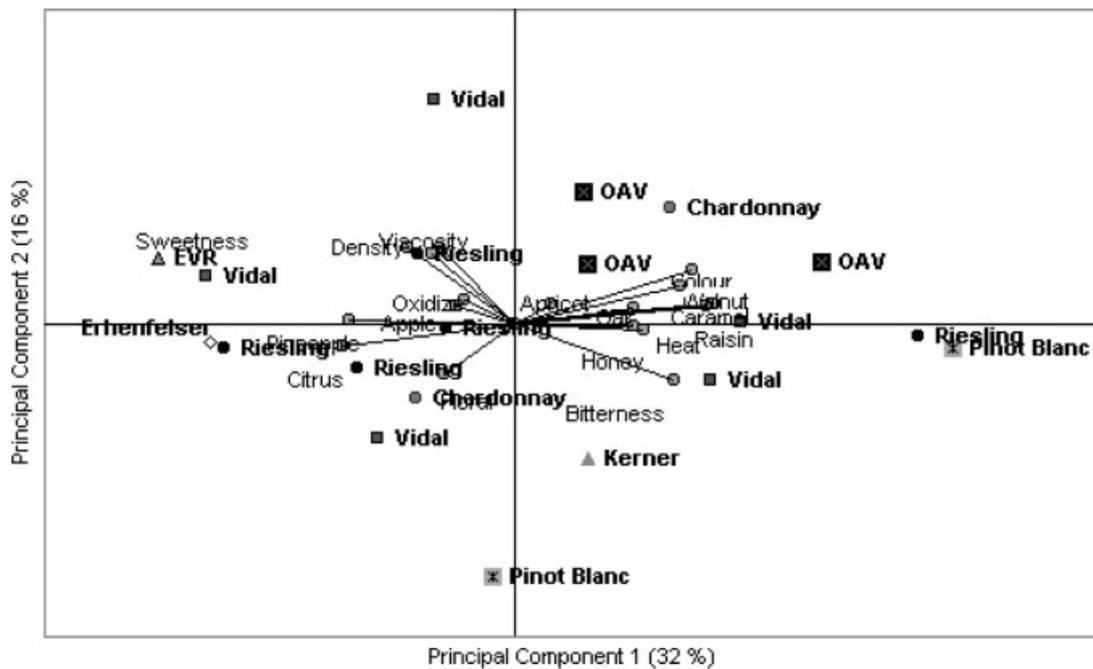


Figure 5. Principal component analysis of mean sensory scores for icewines produced from attributes of Vidal ($n = 8$), Riesling ($n = 5$), Chardonnay ($n = 2$), Pinot Blanc ($n = 2$), Erhenfelfser ($n = 1$), Erhenfelfser–Vidal–Riesling (EVR), ($n = 1$), Kerner and ($n = 1$). OAV, oak-aged Vidal.

impact ice wine composition and quality. The key impact compounds contributing to ice wine aroma and flavour have not yet been clearly defined. Once identified, further work could focus on how these components can be manipulated through the grape-growing and winemaking process. Limitations in sample size and representation did not allow for an examination of how ice wine composition and quality varies between sub-regions or appellations within Ontario and British Columbia. There is much interest in delineation of appellations in Canada presently, and such research would inform this debate.

ACKNOWLEDGEMENTS

The Natural Sciences and Engineering Research Council of Canada is gratefully acknowledged for its financial support of this research. The authors also sincerely thank the Canadian Wine Library and individual wineries from Ontario and British Columbia for their donations of wine for this project. Finally, thank you to all the panellists in this study for your valuable contribution and also Amanda Bartel for carrying out some chemical analysis.

REFERENCES

- 1 Agriculture and Agri-Food Canada (AAFC), The Canadian Wine Industry Sub Sector Profile; www.agr.gc.ca/food/profiles/wine/wine_e.html (Accessed 5 April 2004).
- 2 Cliff M, Yuksel D, Girard B and King M, Characterization of Canadian Ice wines by sensory and Compositional Analyses. *Am J Enol Vitic* 53:46–53 (2002).
- 3 Shaw AB, The emerging cool climate wine regions of Eastern Canada. *J Wine Res* 10:79–94 (1999).
- 4 Shaw AB, Pelee Island and Lake Erie North Shore, Ontario: a climatic analysis of Canada’s warmest wine region. *J Wine Res* 12:19–37 (2001).

- 5 Schreiner J, *Icewine, The Complete Story*. Warwick, Toronto, p 344 (2001).
- 6 Chisholm MG, Guiher LA and Zaczekiewicz SM, Aroma characteristics of aged Vidal blanc wine. *Am J Enol Vitic* 46:56–62 (1995).
- 7 Gallander JF, Effect of grape maturity on the composition and quality of Ohio Vidal blanc wines. *Am J Enol Vitic* 34:139–141 (1983).
- 8 Fischer U, Roth D and Christmann M, The impact of geographic origin, vintage and wine estate on sensory properties of *Vitis vinifera* cv. Riesling wines. *Food Qual Prefer* 10:281–288 (1999).
- 9 Chisholm MG, Guiher LA, Vonah TM and Beaumont JL, Comparison of some French-American hybrid wines with white Riesling using gas chromatography–olfactometry. *Am J Enol Vitic* 45:201–212. (1994).
- 10 Amerine MA and Roessler EB, *Wines: their Sensory Evaluation*, 2nd edn. Freeman, New York, pp 374–378 (1983).
- 11 Amerine MA and Ough CS, *Wine and Must Analysis*. Wiley, New York, p 121 (1974).
- 12 Nurgel C and Pickering G, Contribution of glycerol, ethanol and sugar to the perception of viscosity and density elicited by model white wines. *Food Qual Prefer* (in press).
- 13 Noble AC, Arnold RA, Buechsenstein J, Leach EJ, Schmidt JO and Stern PM, Modification of a standardized system of wine aroma terminology. *Am J Enol Vitic* 38:143–146 (1987).
- 14 Noordeeloos S and Nagel CW, Effect of sugar on acid perception in wine. *Am J Enol Vitic* 23:139–143 (1972).
- 15 Martin M, Minard A and Brun O, Sweetness, sourness and total taste intensity in Champagne Wine. *Am J Enol Vitic* 53:6–13 (2002).
- 16 Martin N, Sweet/sour balance in champagne wine and dependence on taste/odour interaction. *Food Qual Prefer* 7:295–305 (2002).
- 17 Zoecklein BW, Fugelsang KC, Gump BH and Nury FS, *Wine Production and Wine Analysis*. Chapman & Hall, New York, pp 401–418 (1990).
- 18 Nykäenen L and Suomalainen H, *Aroma of Beer, Wine and Distilled Alcoholic Beverages*. Reidel, London, pp 13–25 (1983).
- 19 Rankine BC and Bridson DA, Glycerol in Australian wines and factors influencing its formation. *Am J Enol Vitic* 22:6–12 (1971).

- 20 Romano P, Suzi G, Comi G, Zironi R and Maifreni M, Glycerol and other fermentation products of apiculate wine yeasts. *J Appl Microbiol* **82**: 615–618 (1997).
- 21 Pigeau G, Martin S, Pitkin C and Inglis D, The hyperosmotic stress response of wine yeast induced by fermentable sugars during Icewine fermentation and its relation to gene expression and metabolites specific to this wine, in *Proceedings of the International Bacchus to The Future Conference*, St Catharines, Ontario, 23–25 May, Ed by Cullen CW, Pickering GJ and Phillips R, Brock University Press, pp 177–178 (2002).
- 22 Pitkin C, Kontkanen D and Inglis D, The effects of varying soluble solids concentration in Icewine juice on metabolite production by *Saccharomyces cerevisiae* K1-V1116 during fermentation, in *Proceedings of the International Bacchus to The Future Conference*, St Catharines, Ontario, 23–25 May, Ed by Cullen CW, Pickering GJ and Phillips R, Brock University Press, p 179 (2002).
- 23 Noble AC and Bursick GF, The contribution of glycerol to perceived viscosity and sweetness in white wine. *Am J Enol Vitic* **35**:110–112 (1984).
- 24 Kosmerl T, Abramovic H and Klofutar C, The rheological properties of Slovenian wines. *J Food Eng* **46**:165–171 (2000).
- 25 Lopez A, Ibarz A, Pagan J and Vilavella M, Rheology of wine musts during fermentation. *J Food Eng* **10**:155–161 (1989).
- 26 Bayindirli L, Density and viscosity of grape juice as a function of concentration and temperature. *J Food Proc Preserv* **17**:47–151 (1993).
- 27 Hollowood TA, Linforth RST and Taylor AJ, The effect of viscosity on the perception of flavour. *Chem Senses* **27**:583–591 (2002).
- 28 Morris ER, Concentration and shear rate dependence of viscosity in random coil polysaccharide solutions. *Carbohydr Polym* **1**:5–11 (1981).
- 29 Smith AK, June H and Noble AC, Effects of viscosity on the bitterness and astringency of grape seed tannin. *Food Qual Prefer* **7**:161–166 (1996).
- 30 Smith AK, June H and Noble AC, Effects of increased viscosity on the sourness and astringency of aluminum sulfate and citric acid. *Food Qual Prefer* **9**:139–144 (1998).
- 31 Mottiar S, The determination of the inoculating yeast as a producer a high levels of acetic acid in ice wine production. BSc Thesis, Department of Biological Sciences, Brock University (2000).
- 32 Bisson LF, Stuck and sluggish fermentation. *Am J Enol Vitic* **50**:107–119 (2003).
- 33 Etievant P, Wine, in *Volatile Compounds in Food and Beverages*, Ed by Maarse H. Marcel Dekker, New York, pp 145–149 (1991).
- 34 Daudt CE and Ough CS, Variation in some volatile acetate esters formed during grape juice fermentation. Effects of fermentation temperature, SO₂, yeast strain and grape variety. *Am J Enol Vitic* **24**:3–7 (1973).
- 35 Nurgel C, Yeast flora during the vinification Emir and Kalecik Karasi cultivars and effect of inoculation of selected yeasts on wine quality. PhD Thesis, Institute of Natural and Applied Sciences, University of Cukurova (2000).
- 36 Pickering GJ, Heatherbell DA and Barnes MF, The production of reduced-alcohol wine using glucose oxidase-treated juice II—SO₂-binding and stability. *Am J Enol Vitic* **50**:299–306 (1999).
- 37 Main GL and Morris JR, Color of Riesling and Vidal wines as affected by bentonite, CufexRegistered, and sulfur dioxide juice treatments. *Am J Enol Vitic* **42**:354–357 (1991).
- 38 Langstaff SA, Guinard JX and Lewis MJ, Instrumental evaluation of the mouthfeel of beer and correlation with sensory evaluation. *J Inst Brewing* **97**:427–429 (1991).